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Quantifying the Effect of Passive Solar Design in Traditional New England Architecture

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QUANTIFYING THE EFFECTS OF PASSIVE SOLAR DESIGN IN TRADITIONAL NEW ENGLAND ARCHITECTURE

A Thesis Presented

By

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ABSTRACT

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MAY 2014

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Passive solar design can be an effective means of reducing conditioning loads in residential buildings by utilizing free solar heat during the heating season, and blocking unwanted solar heat during the cooling season. The objective of this thesis was to use energy modeling software to simulate the effect that incorporating passive solar design strategies into typical New England style houses would have on their energy usage for heating and cooling. The designs that were studied were Capes, Colonials, and Saltboxes. Four versions of increasing energy efficiency were studied for each style. After measuring baseline energy usage for each model, four passive solar variables were incorporated: orientation, allocation of windows to southern façade, shading devices, and thermal mass. After determining the ideal orientation of each building, 300 combinations of window allocation, shading device depth, and amount of thermal mass were simulated for each model. From this pool of simulations, the model with the

lowest conditioning costs was selected and compared to its respective baseline design. As a general trend for each style, as the level of energy efficiency decreased, the savings from incorporating passive solar design increased. For the colonial models, the savings ranged from $422-$150. For the Saltbox models, the annual savings ranged from$398-$116. For the Cape models, the savings ranged from $303-$75.

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CHAPTER 1

PASSIVE SOLAR DESIGN

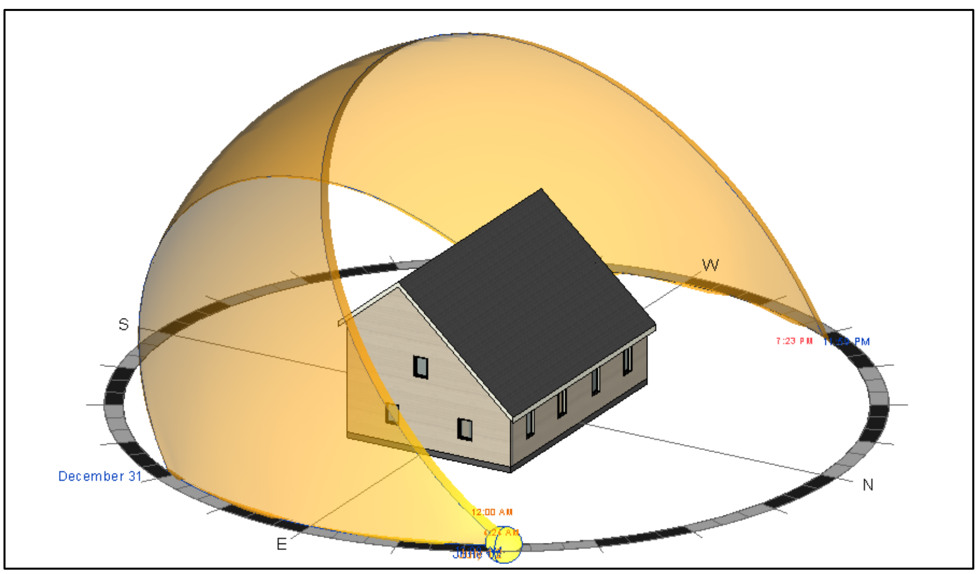
1.1 Introduction

In the United States, buildings account for nearly 40 percent of energy consumption (EERE,2008). Residential buildings are responsible for 55 percent of this (EERE, Building Sector, 2011). The main sources of energy consumption in residential buildings are heating and cooling, accounting for 45 percent and 9 percent respectively on a national basis (DOE, Residential Sector, 2011). In the Northeast, heating and cooling account for 57 percent and 3 percent of energy consumption respectively (EERE, Residential Energy Consumption 2011). In New England the fuels used for heating are fuel oil (49 percent), utility gas (33 percent), electricity (11 percent), and bottled natural gas and liquid propane (4 percent) (U.S. Census of Housing, 2000). Electricity is also responsible for all of the cooling loads. Nationally, 42% of electricity is generated from coal, 25% from natural gas plants, 19% from nuclear, 13% from hydroelectric and other renewables, and 1% from petroleum and other sources. (EIA, 2012) As fuel oil, natural gas, and the majority of electricity are harvested from nonrenewable, greenhouse gas producing sources, it is important to find alternative means of heating and cooling which do not rely on these unsustainable resources.

Minimizing the need for these unsustainable resources in residential buildings is being addressed in a variety of ways, such as bolstering thermal envelopes, minimizing infiltration, optimizing Heating Ventilation and Air Conditioning (HVAC) systems, utilizing a variety of on-site energy production systems, and using renewable fuel sources like wood or wood pellet for heating. While many architects, builders, developers, and policy makers have come to realize the importance of these measures, one practice which often goes overlooked is the use of passive solar design.

Passive solar design is simple in principle. It relies on our understanding of where the sun is going to be at any given time on any particular day of the year. In the Northern hemisphere the sun rises in from the east, crosses the southern sky throughout the day, and sets in the west. The sun is lowest in the sky on the winter solstice and highest in the sky on the summer solstice. (See figure 1) The exact angle of the sun on any these days, and any others is relative to the latitude of the location in question.

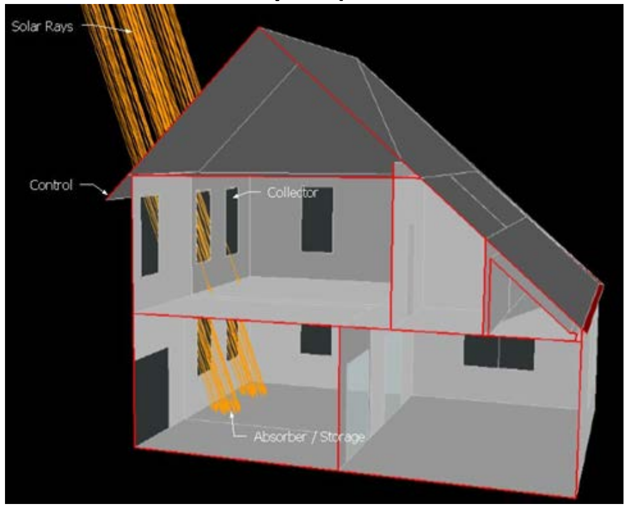
Figure 1: Sun Path Diagram (Created in Autodesk Revit)



Passive solar design relies on the use of controlled passive solar radiation to provide heating when desired, and protection from overheating when it is unwanted. For passive solar design to be successful, it must incorporate 5 main principles. (See figure 2) (1) Collector: There must be abundant apertures in the southern façade. (2) Absorber: There must be absorbent surfaces which can transfer insolation from a surface into storage. (3) Storage: There must be thermal mass that can store the absorbed energy. (4) Distribution: There must be a means to transport this heat, either mechanically or passively throughout the building. (5) Control: There needs to be a way to control solar radiation in warmer months, when it is not wanted. (NREL, 2001).

These principles are implemented through the use of one of three systems: direct gain, isolated gain and indirect gain (Winter Associates,1998). This research focuses on the direct gain approach, as this approach does not rely on adding features that would not be found in traditional New England architecture. With this approach, distribution can be largely ignored, as the solar radiation is striking areas within the conditioned space. Distribution is necessary in the other approaches as the areas being heated with insolation are not within the conditioned spaces, and therefore the heat needs to be transported to them. I therefore focused on collection, storage and control, as well as orientation, which has implications on all of these variables.

Figure 2: Passive Solar Principles (Created in AutoDesk Ecotect)



Solar energy can be stored in buildings through the use of thermal mass. In order to be effective, the materials used for thermal mass must have a high thermal storage capacity. This capacity is dictated primarily by a material's density, thickness, conductivity and specific heat (See table 1). Conductivity indicates a materials ability to transfer (conduct) heat. The higher the conductivity of a material, the faster heat will travel through it. Specific heat (or heat capacity) is the amount of heat energy required to raise the temperature of a given unit of mass by 1 degree.

Q = (c)(m)(delta T)

Where:
Q = Heat
C = Specific heat
M = mass
Delta T = Temperature difference

Table 1: Thermal Storage Capacity of Common Building Materials

Material	Specific heat (Btu/lb_m°F)	Specific Heat (Btu/ ft^3/°F) Calculated from average Density	Thermal Conductivity (Btu/(hr°Fft))	Density (lb/ft^3)
Brick	0.22	24.6	0.34 - 0.5779	87-137
Concrete	0.23	33.4	0.23 - 0.40	140 – 150
Granite	0.19	32	0.98 – 2.31	165 – 172
Wood (Oak)	0.48	21.6	0.069	45
Wood (White Pine)	0.6	15.9	0.09	22 – 31

(Source: Engineering Toolbox: Specific Heat, Thermal Conductivity, Density)

It is important to note that while wood has a higher specific heat than brick or concrete, it has a significantly lower density, and because the units for specific heat are based on mass not volume, the specific heat values can be misleading. For example, the specific heat of white pine is almost 3 times higher than concrete, however concrete is approximately 6 times denser than white pine. This means that if an equal volume were used, concrete would have a significantly higher thermal storage capacity.

Thermal mass can be added to a building in the form of poured concrete or concrete masonry units (CMU). Poured concrete is often used for a flooring material. CMUs are often used to build walls. Poured concrete and CMUs typically serve a dual purpose, as structural components as well as a source of thermal mass. Other materials with high thermal storage capacity, such as ceramic tile, stone and brick can be used for flooring, fireplaces, and other purposes, in order to provide additional thermal mass.

Studies on the effect of storage (thermal mass) in buildings have had varying results. This is a function of the differing methods of applying thermal mass, as well as the different climates in which they are used. A study of South facing thermal mass walls in Cyprus, found that properly constructed thermal mass walls could reduce heating loads in adjacent zones by 47%, while raising cooling loads by 4.5% (Florides, et al 2002). Another study showed that in the heating dominated climate of Minneapolis, Minnesota, when traditional wood framed walls were replaced with high thermal mass, concrete walls, the buildings experienced an 8% energy savings throughout the heating season. The same study showed that in the cooling dominated climate of Bakersfield, California, replacing wood stud walls with concrete walls resulted in a 5-18% energy savings throughout the cooling season (Childs, et al. 2001).

Window shading has also been studied extensively, but once again, the effect varies greatly as a result of the type of shade, and the climate that the building is in, as well as the orientation of the façade being shaded. It is estimated that in some climates, solar radiation increases cooling requirements of un-shaded buildings by up to 25% (Mingfang, 2000). One thing that is commonly agreed on is that the most effective means of preventing unwanted solar gains is to use exterior shades (McCluney, et al. 1993). These are more effective than interior shades, because although interior shades reflect light, they do so after the light has penetrated the room and has heated some interior air and materials.

As with the other variables, the effect of orientation is highly variable as a result of location, however, a study looking at 25 different areas in the United States, found that when the most extensively glazed façade faced south, it would have lower total energy use than the same building if it faced East or West (Anderson, et al. 1985).

All of these variables can be studied and measured using energy modeling software. I will be using Design Builder, which uses the EnergyPlus simulation engine, which was developed by the U.S. Department of Energy. With regard to thermal mass,

> DesignBuilder uses the thermal characteristics of the constructions for each of the walls, floors, roofs, partitions etc. in each zone and accounts for the thermal mass in the simulations. You can also include additional thermal mass to account for partitions within a zone, furniture and any other mass which will affect the dynamic thermal response of the zone. (Internal Thermal Mass, Design Builder)

With regard to the other variables,

> The EnergyPlus daylighting model, in conjunction with the thermal analysis, determines the energy impact of daylighting strategies based on analysis of daylight availability, site conditions, window management in response to solar gain and glare, and various lighting control strategies. (EnergyPlus Daylight Calculations, Design Builder)

While the principles of passive solar design are well known, what is not well known and is often of utmost importance when the decision is being made whether or not to incorporate them, is how much passive solar design actually reduces the need for mechanical heating and cooling in typical styles of residential construction. This lack of knowledge stems from the fact that useful calculations are inherently region, and building type specific. Additionally, there are many energy conservation variables outside the scope of passive solar design which are necessary for an energy efficient building (Winter Associates, 1998).

CHAPTER 2

METHODOLOGY

This research focused on measuring the effects of four passive solar design variables (building orientation, window to wall ratio (WWR) on the southern façade, implementation of shading mechanisms and the amount of thermal mass). The buildings that were studied are typical examples of Colonial, Saltbox, and Cape style homes built in the Northeastern United States. The buildings are designed according to typical materials and construction practices, and varying levels of energy efficiency.

2.1 Building Design

Each style was constructed according to how that style is typically built. The average square footage for new residential construction in the Northeastern U.S. is 2,600ft^2. (U.S. Census, 2010). This square footage was used for the colonial model. With ceiling heights of 8' it had a volume of 20,880ft^3. Both the Saltbox and Cape styles tend to be smaller than colonials, largely due to the reduced availability of second floor space. The total square footage for the saltbox and cape styles was dictated by keeping the footprint the same as the colonial, and utilizing the available second floor space. This resulted in an area of 2,400ft^2 for the saltbox with a volume of 19,333 ft^3, and an area of 2,125ft^2 for the cape, with a volume of 17,400 ft^3.

The dimensions of the footprint were determined by finding the average length to width ratio of the colonial. This was done by studying aerial imagery of 25 randomly selected colonials in Amherst Massachusetts, and measuring their footprints (Appendix A). This study found an average length to width ratio of 1.45/1. A two story, 2,600ft^2 colonial has a footprint of 1300 ft^2. With a length to width ratio of 1.45/1, a 1300 ft^2 footprint is 43.5' long by 30' wide.

The typical window to wall ratio for each style was also determined by studying oblique aerial imagery of 25 randomly selected colonials and capes and measuring the window area and wall area of the front, sides, and rear facades (Appendix A). The Images used in this study were gathered from the public Pictometry viewer, provided through the town of Amherst MA, public GIS site. The WWR of the saltbox was determined by using the values from the front and side facades of the colonial, and the rear façade of the cape (as the rear façade of the saltbox is one story).

Figure 3: Pictometry Viewer Front View

The colonial had an average WWR of 12.4% for the front façade, 5.2% for the side facades, and 11.6% for the rear façade. The Cape had an average WWR of 12.6% for the front façade, 6.9% for the side facades, and 11.3% for the rear façade.

Table 2: Calculated Window to Wall Ratio for Colonial, Cape and Saltbox

	Colonial	Cape	Saltbox
Front Façade WWR (%)	12.4	12.6	12.4
Side Facades WWR (%)	5.2	6.9	5.2
Rear Façade WWR (%)	11.6	11.3	11.3

2.2 Non Passive Solar Attributes

Given the variability in general construction practices, it is important to model the effects of passive solar design at varying levels of energy efficiency. Therefore I created four levels of energy efficiency, in which the envelope related variables are manipulated according to four increasingly stringent sets of standards. (See tables 3-6) The non-envelope related variables are kept constant at the default values for DesignBuilder's 2000 IECC lightweight Template.

In order to better illustrate these levels, I calculated the Home Energy Rating System (HERS) index that each achieves relative to the colonial style. The HERS index is a measure of how energy efficient a building is relative to a theoretical geometric replica built according to the Residential Energy Network (RESNET) standards which are based on the 2006 IECC. The score represents what percent of the energy use of the reference house is used by the real house. For example a HERS index of 95 means that the real house uses 95 percent of the energy of the reference house. HERS ratings account for everything from the envelope, to HVAC system and appliance efficiencies. For the purpose of these HERS scores, the non-envelope related variables were kept at the RESNET reference house values within the REM/Rate software with which the calculations were done. This is because many of the non-envelope related variables are beyond the control of the architect, and lowering them would require potentially untrue assumptions. As a result, these HERS scores are higher than would often be found in houses in which non envelope related energy efficiency measures were taken. The HERS scores were calculated using the software REM/Rate™ which is produced by Architectural Energy Corporation specifically for calculating HERS index scores.

The least energy efficient model is designed to represent typical construction practices. This model is based on the requirements of the Massachusetts 8th Edition Building Code. Relevant codes from this are taken from the 2009 International Energy Conservation Code (IECC). (Mass.gov, 2012) This Model scores a HERS index of 95.

Table 3: Envelope Related Variables for IECC 2009 Models

External Wall	U-Factor- 0.057 (R-18)
Roof	U-Factor – 0.030 (R-33)
Slab	U-Factor – 0.10 (R-10)
Windows	U-Factor- 0.35
Doors	U-Factor - 0.35
Infiltration	ACH50=7

(IECC 2009, 402.1.3)

The next level of energy efficiency was built according to Energy Stars Prescriptive Path Method. The only variables that were changed from the 2009 IECC were those relevant to the Envelope (Wall, roof, floor and door R-values, window U-values, and infiltration rate. This model scores a HERS index of 82.

Table 4: Envelope Related Variables for Energy Star Models

External Wall	U-Factor- 0.057 (R-18)
Roof	U-Factor – 0.030 (R-33)
Floor	U-Factor – 0.10 (R-10)
Windows	U-0.25
Doors	U-0.21
Infiltration	ACH50=4

(Energy Star, 2012)

The most energy efficient was built according to typical Passive House construction in the New England area. In order to quantify this, I looked on the Passive House U.S. website, on which all of the Passive Houses that have been built, or are pre-certified to be built in the New England, have various specs published. From these specs, I found the average R-values for Roofs, Walls and Floors, the average Infiltration rates, and the windows that were used for each (Appendix C). This model scores a HERS index of 62.

Table 5: Envelope Related Variables for Passive House Models

External Wall	U-Factor – 0.0208 (R-48)
Roof	U-Factor – 0.0125 (R-80)
Slab	U-Factor – 0.022 (R-45)
Windows	U-0.15
Doors	U-0.21
Infiltration	ACH50=0.45

(Passive House, 2012)

Additionally, there is a level of energy efficiency for which the HERS index is the average of Energy Star and Passive House and the envelope related variables are calculated accordingly. This model was made because many houses are built to be significantly more energy efficient than Energy Star requires, yet not as efficient as Passive House. This model has a HERS index of 72.

Table 6: Envelope Related Variables for Energy Star - Passive House Average Models

External Wall	U-Factor – 0.033 (R-30)
Roof	U Factor – 0.02 (R-50)
Slab	U-Factor – 0.036 (R-28)
Windows	U-0.22
Doors	U-0.21
Infiltration	ACH50=3.0

In addition to the envelope related variables, all models included a variety of other necessary input data. Designbuilder comes pre-loaded with many templates, which contain appropriately chosen default values. IECC 2000 data is the most recent IECC template available, so they were used. Values were only changed if they were envelope related variables, not specified in the template, or if the IECC 2009 Simulated Performance table provides a conflicting value. The exhaustive list of inputs can be found in appendix B.

2.3 Simulations

Simulations were done by creating building information modeling (BIM) models of each house using Autodesk® Revit®. These models were then imported into Design Builder for analysis. There were 4 tiers of analysis done in Designbuilder. (1) A baseline simulation, for each architectural style, with each type of construction practices. (2) A set of simulations in which orientation is explored. (3) A set of parametric simulations in which every combination of WWR, shading and thermal mass is explored (4) A simulation of each style and construction practice with all variables at their optimal level, which was then compared to the baseline models in order to quantify the effect of the passive solar strategies.

Tier 1: In order to give meaning to the results, baseline values needed to be calculated for each structure. These simulations show how the structure operated before the incorporation of passive solar design. In this set of simulations, four data sets were created for each architectural style, one according to each level of energy efficiency. For these simulations, the buildings will be treated as if they were constructed with no regard for passive solar design. They were oriented with the long axis facing East-West. They had typical window to wall ratios, as dictated by their architectural styles, no shading devices, and no extra thermal mass.

From this point on, subsequent manipulations were done the same way for all four levels of energy efficiency for each architectural style, therefore, the following descriptions are a generic outline that was applied to each architectural style and construction practice.

Tier 2: These simulations show the effect of orientation on the baseline design. Each model was rotated at 10 degree increments for 360 degrees. These simulations demonstrated that the model operated best when the front faced due South. After this was demonstrated, and therefore established which façade should face south, the solar heat gain coefficient (SHGC) for the front façade was changed to 0.65. The models were than rotated again at 45 degree increments. SHGC is the fraction of solar radiation that is transmitted through a window, door, or skylight. It is represented as a figure between 0.0-1.0. The higher the SHGC, the more solar radiation will be transmitted through that aperture, and the more solar heating will occur as a result. The lower the SHGC, the less solar radiation will be transmitted though, resulting in a reduction of heating. As a rule, the windows on the North, East and West facades should have a low SHGC, while the windows on the South façade should have a SHGC of at least 0.6. (EERE, Passive Solar Window Design, 2011).

Tier 3: Once it was established that the front façade facing south provided the best opportunity for passive heating and cooling techniques, the other variables were applied. Using the parametric simulation feature in Designbuilder, I was able to run multiple simulations in which the value of two variables (Depth of shading device, and Thermal Mass) were varied. This was then done for varying levels of WWR. This set of simulations show the effect of every combination of WWR, shading, and thermal mass according to a predefined set of increments.

Window to Wall Ratio: Windows were incrementally removed from the East, West, and North facades and added to the South façade. This was done in two window increments. For the colonial and Saltbox designs there was room to relocate 10 windows to the southern façade, changing the WWR on the south facade from an initial 12.4 to 26. For the Cape model, there was room to relocate 6 windows, changing the WWR on the south facade from an initial 12.6 to 31.5. There was no net change in window area for any of the buildings, just a reallocation of existing windows. The only change to the windows that were moved was that their SHGC was changed to that of the other windows on the southern façade.

Control (Shading): Shading devices were implemented in two ways. For first floor windows a window overhang was constructed that was located 9” above the tops of the windows and extended 9” beyond both sides of the windows. The second floor windows were shaded by the roof overhang, which was also located 9” above the tops of the windows. For both types of shade, the depths were increased in 4” increments from 0”-36”. The default roof overhangs were 12”, so the first 12” of increased overhang only affected the first floor. Once the first floor had a 12” overhang, both the first and second floor overhangs were increased together at 4” increments up to 36”.

Thermal Mass: The thermal mass was added by increasing the thickness of the concrete slab on the first floor. The default thickness of the concrete was 4”. The thickness was increased at 2 inch increments, up to 12 inches.

With these 3 variables varying at their respective increments I was able to simulate all of the potential combinations that could occur. For the colonial and saltbox, this meant 6 variations of WWR, 10 variations of overhang depth, and 5 variations of thermal mass. This totaled to 300 potential combinations of WWR, overhang, and thermal mass. The cape had 4 variations of WWR, 10 variations of overhang depth, and 5 variations of thermal mass. This totaled to 200 potential combinations. This process was done for each level of energy efficiency, for each architectural style. From these sets of simulations I was able to find the optimal combination of values which provided the lowest conditioning cost for each building.

To find the optimal design, there are two main tracks to follow. One track is to optimize by energy cost, in which all decisions are made based on how much money will be spent to run the mechanical systems. With this method, you are balancing the decreased cost of heating with the subsequent increased cost of cooling as a result of overheating. The other track is to optimize by how comfortable the building is, i.e. which design results in the least amount of time in which the interior conditions are outside the desired set-points. These two methods sway the optimized design in different directions.

Designing purely for cost becomes problematic with regard to overheating from solar gains during the winter when air conditioners are typically turned off. Throughout the rest of the year there is an active mechanical system to address cooling during the summer and heating in the winter. This need for heating and cooling is reflected in the energy loads and subsequent costs. However, because air conditioners are typically not active in the winter when the temperature rises above the set-point, there is a need for cooling, but no cooling is supplied, therefore no energy is used so there is no reported cost. This means that with cost optimization, overheating in the winter does not play an active role in design decisions. Ultimately you get a building that is the least expensive to condition, but may be chronically overheating in the winter.

Conversely, if the design is optimized by comfort, as most building are, all measures will be taken to minimize solar gains and rely exclusively on the mechanical heating and cooling. This will result in a building that is always at the set-point temperatures, but is more expensive to condition, as it minimizes the use of passive solar energy.

I found it important to find a way to optimize the design by cost, but in a manner that also took into account the discomfort from overheating during winter transition months. In order to do that, for the design optimization simulations, the air conditioning was activated year-round. This resulted in a reporting, in the form of required cooling energy and subsequent cost of how much overheating was occurring. This allowed for a cost optimization that included the discomfort felt from overheating in the winter.

Once the optimal design was realized using this method, the tier 4 simulations were done with the air conditioning deactivated for the winter months, which gives a more realistic representation of typical energy use.

Tier 4: These simulations show how each building operates after it is oriented such that the front facade faces south, the window area on the southern façade is increased, shading devices are implemented, and thermal mass is added at the combination of values that provided the lowest conditioning costs. These data sets are then compared to their respective baseline data sets in order to quantify the effect of passive solar design on each building.

CHAPTER 3

RESULTS

The simulations were run for each building and the results were gathered. The simulations described the necessary heating and cooling loads for each building. From these loads, the annual conditioning costs were calculated based on the appropriate system efficiencies and fuel costs. After this was done for every variation of each building, the optimal configuration of passive solar features was found and the operating cost of the optimal design was compared to the baseline design.

3.1 Colonial

Figure 4: Colonial House

3.1.1 IECC 2009 Colonial

In order to observe the effect of orientation on the baseline design, the model was rotated 360° at 10° increments. For these rotations, 0° indicates the front façade is facing due South, 90° indicates facing due West, 180° indicates facing due North, and 270° indicates facing due East. As these figures show, the heating load is at its maximum when the front façade, which has the highest percentage of glazing, is facing North. The heating load is minimized when the front is facing due South. Conversly, the cooling load is minimized when the front is facing North, and maximised when it is facing East or West. Facing South also minimizes the cooling load. This is because the existing 1' overhang of the roof provides some shading to the second floor windows when facing south.

Figure 5: IECC 2009 Colonial Orientation Effect on Heating Load

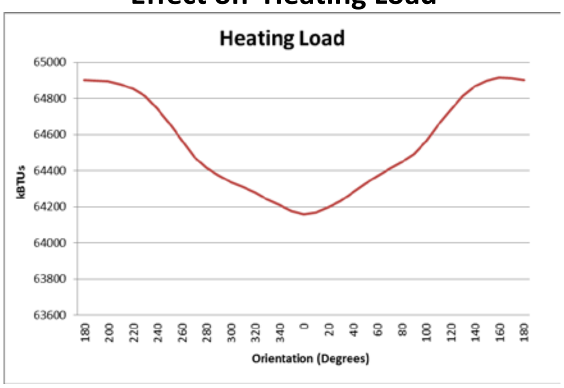
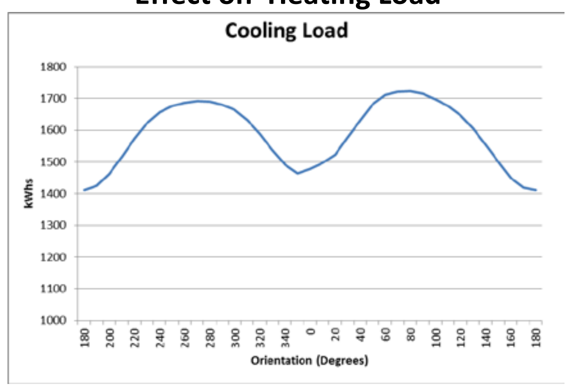


Figure 6: IECC 2009 Colonial Orientation Effect on Heating Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 7: IECC 2009 Colonial Orientation Effect on Conditioning Cost

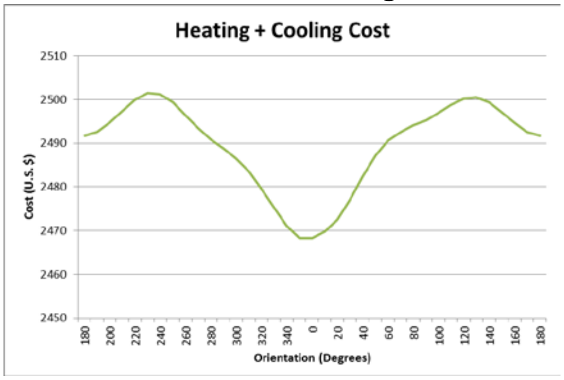
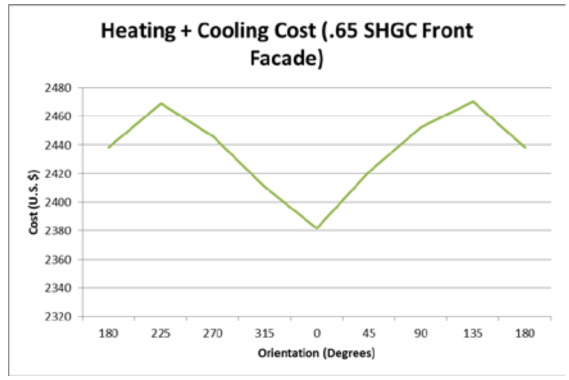


Figure 8: IECC 2009 Colonial Orientation Effect on Conditioning Cost, with .65 Front SHGC



Once it has been established that the optimal orientation is for the front façade to face due south, the appropriate solar heat gain coefficient of .65 can be applied to these windows. With these windows in place, the model is once again rotated, this time at 45° increments. Once again, it is evident that facing due South is the optimal orientation.

By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern façade, the cost has been reduced from $2,495 to $2,381, an annual savings of $114 (4.5%)

With the building at its optimal orientation of 0°, the effect of additional southern glazing, thermal mass, and the addition of shading in the form of window overhangs, can be added. The following figures illustrate the heating load, cooling load, and total cost, of every possible combination of these variables.

The combinations of these three variables are illustrated on sets of surface graphs. The graphs show the effect that the different combinations of thermal mass and overhang depth have on the heating and cooling loads as well as total annual cost. Each set of these graphs is based on an increasing amount of southern WWR, starting at the baseline value of 12.4 and increasing up to 26, at which point there is no room for additonal windows. (The set of graphs shown are from the WWR for the optimal design, in this case, WWR=26. The sets of graphs for the other WWRs can be found in appendix C)

Figure 9: IECC 2009 Colonial Heating Load With WWR=26

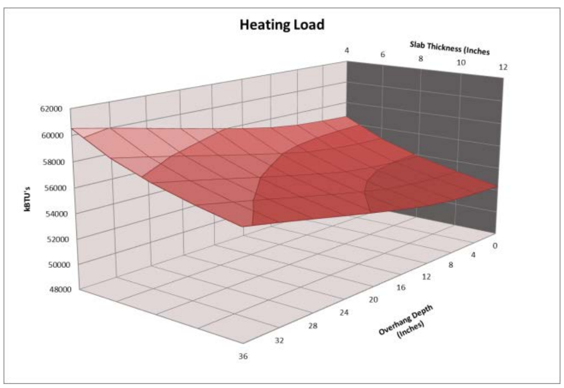


Figure 10: IECC 2009 Colonial Cooling Load With WWR=26

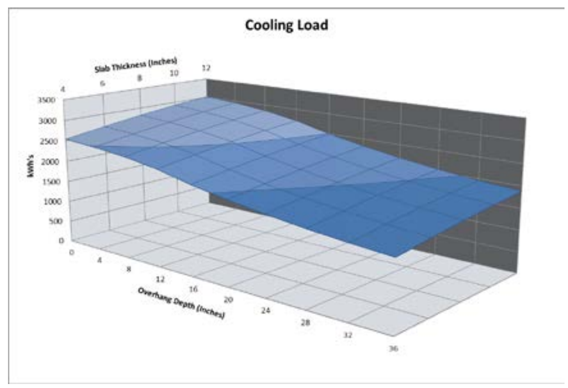
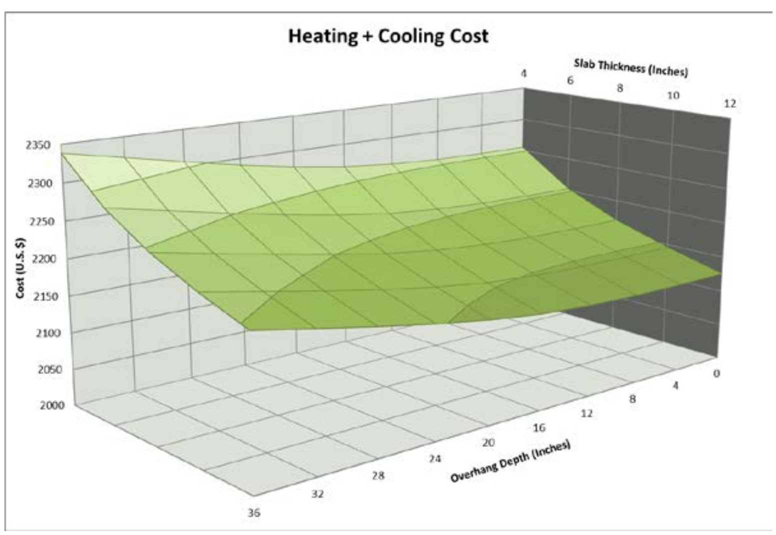


Figure 11: IECC 2009 Colonial Conditioning Cost With WWR=26



The Optimal design for the IECC 2009 Colonial faces due South, has a WWR of 26 percent, a 12” concrete slab, and a 4” window overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 12: IECC 2009 Colonial Baseline Design Daily Internal Gains

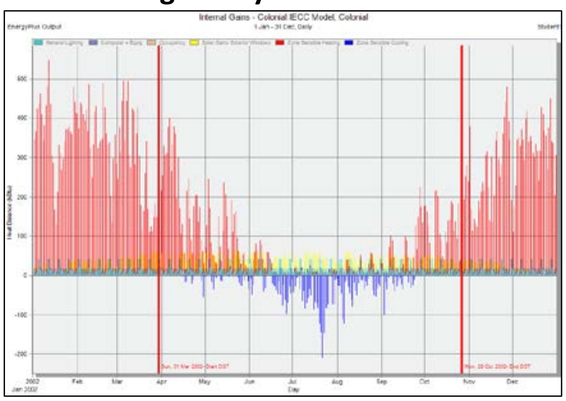


Figure 13: IECC 2009 Colonial Optimal Design Daily Internal Gains

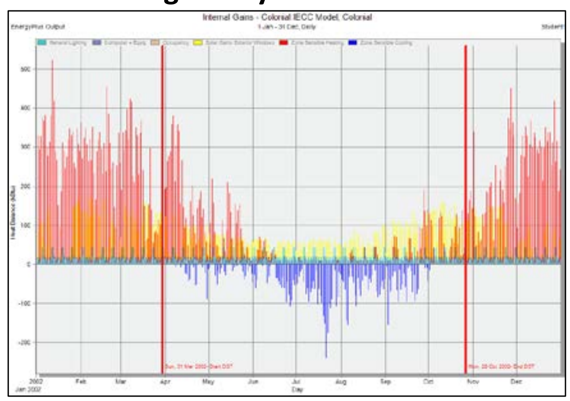


Figure 14: IECC 2009 Colonial Baseline Design Monthly Internal Gains

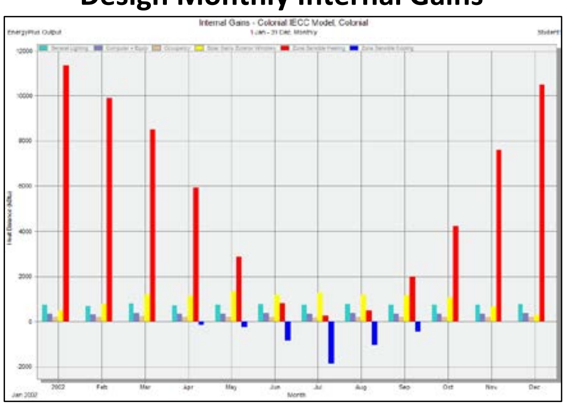


Figure 15: IECC 2009 Colonial Optimal Design Monthly Internal Gains

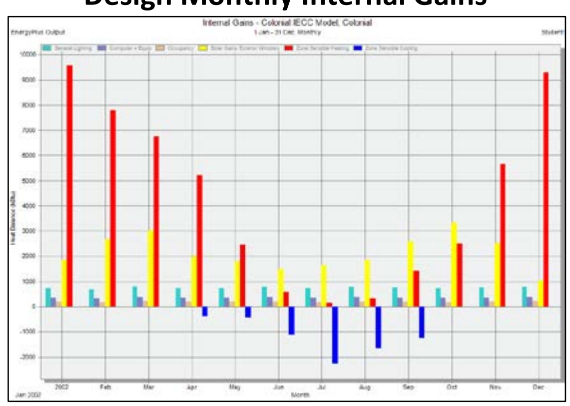


Figure 16: IECC 2009 Colonial Baseline Design Annual Internal Gains

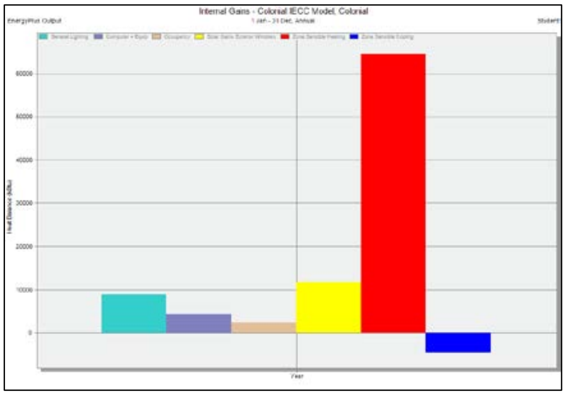


Figure 17: IECC 2009 Colonial Optimal Design Annual Internal Gains

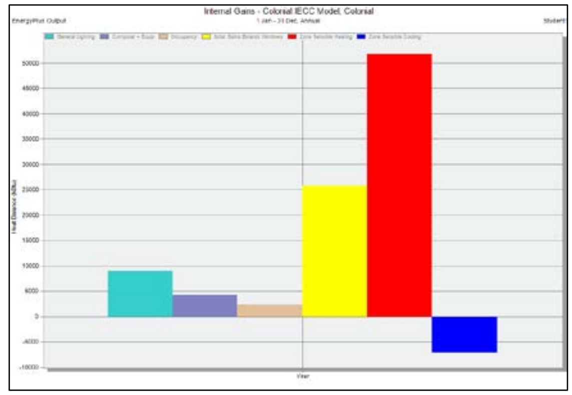


Table 7: IECC 2009 Colonial Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	64,408,000 BTU	-12,723 BTU	Annual Heating Load	51,727,000 BTU
Annual Heating Cost	$2,386	-$472	Annual Heating Cost	$1,916
Annual Cooling Load	1,700 kWh	+687 kWh	Annual Cooling Load	2,480 kWh
Annual Cooling Cost	$104	+$42	Annual Cooling Cost	$152
Total Conditioning Cost	**$2,490**	**-$422 (17%)**	**Total Conditioning Cost**	**$2,068**

By implementing passive solar design into the IECC Colonial, the annual heating load was reduced by 12.7 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $472 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 687 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $42 increase of annual cooling costs. This resulted in a net reduction of $422 (17%) of conditioning costs as a result of implementing passive solar design.

One of the benefits of passive solar design is that it operates independent of outside energy sources, so in extended power outages or other times in which conventional heating is not available, the passive solar gains are still present. The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 18: IECC 2009 Colonial Baseline Design Daily Temperatures Without Mechanical Systems

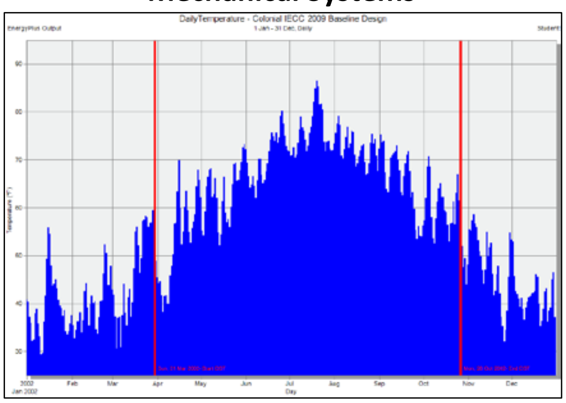


Figure 19: IECC 2009 Colonial Optimal Design Daily Temperatures Without Mechanical Systems

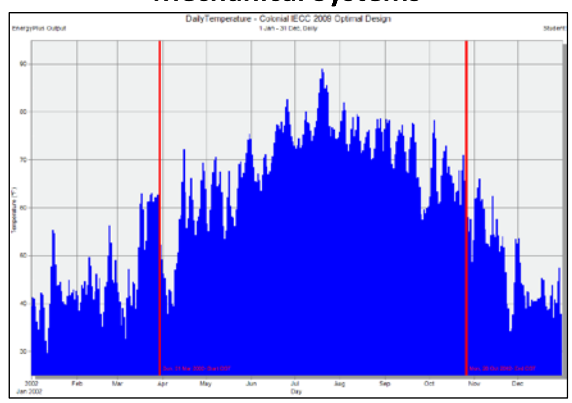


Figure 20: IECC 2009 Colonial Baseline Design Monthly Temperatures Without Mechanical Systems

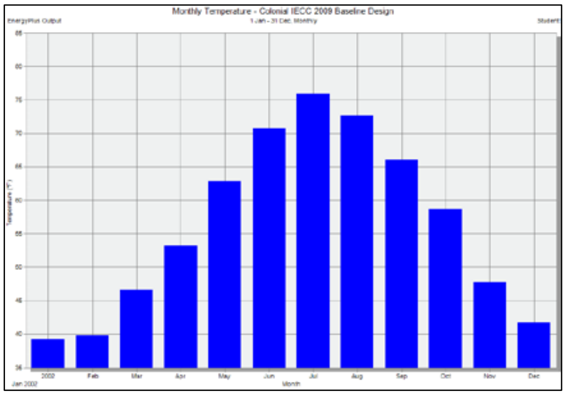
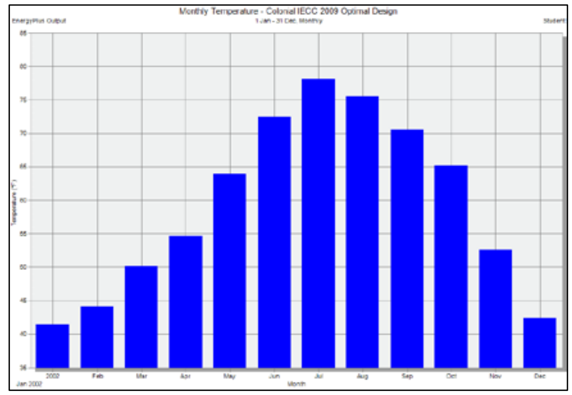


Figure 21: IECC 2009 Colonial Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 3-6° warmer than the baseline design. Additionally, they minimize many of the daily temperature dips below 40°, especially in February and March.

3.1.2 Energy Star Colonial

The effects of orientation on the Energy Star model are quite similar to that of the IECC model. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling. Once again 0° is a close second for cooling as a result of the roof overhang over the second floor windows.

Figure 22: Energy Star Colonial Orientation Effect on Heating Load

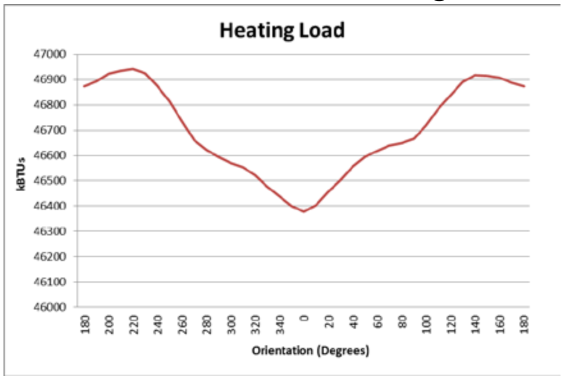
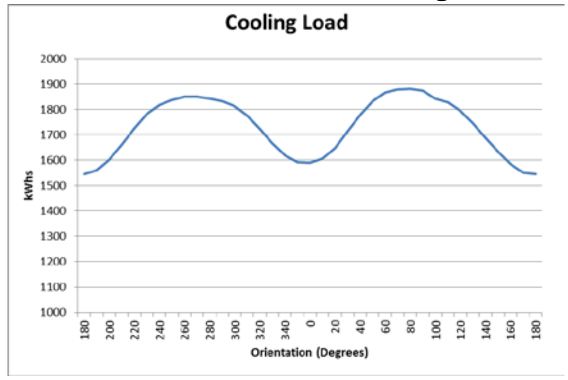


Figure 23: Energy Star Colonial Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 24: Energy Star Colonial Orientation Effect on Conditioning Cost

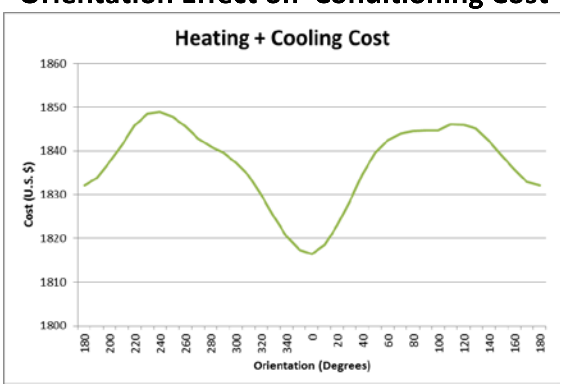
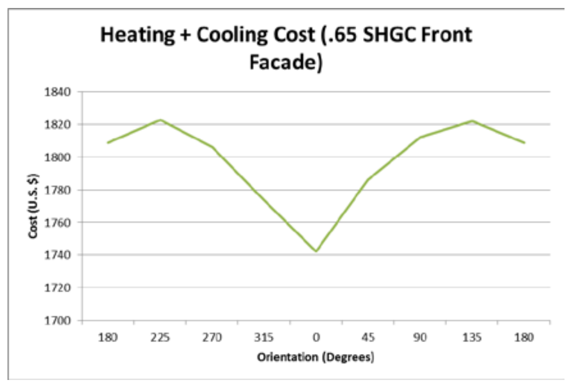


Figure 25: Energy Star Colonial Orientation Effect on Conditioning Cost, with .65 Front SHGC



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the conditioning cost has been reduced from $1,844 to $1,742, a savings of $102 (5.5%)

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design.)

<u>26 WWR:</u>

Figure 26: Energy Star Colonial Heating Load With WWR=26

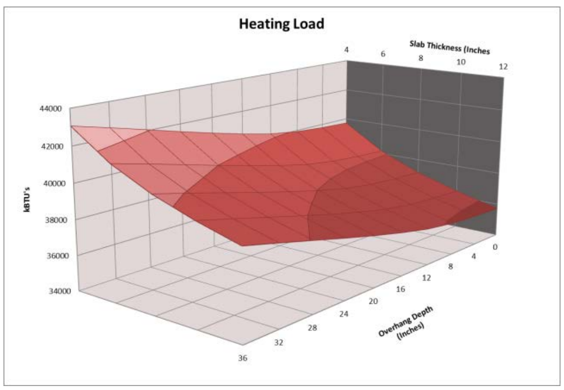


Figure 27: Energy Star Colonial Cooling Load With WWR=26

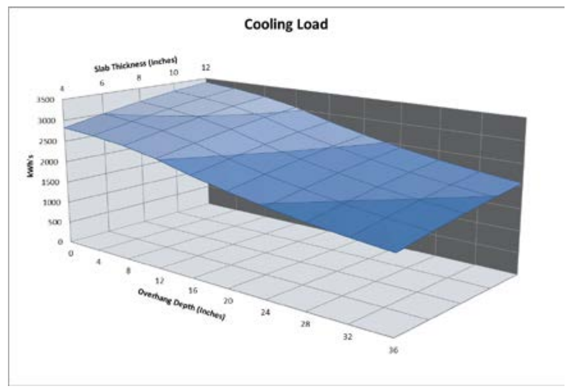
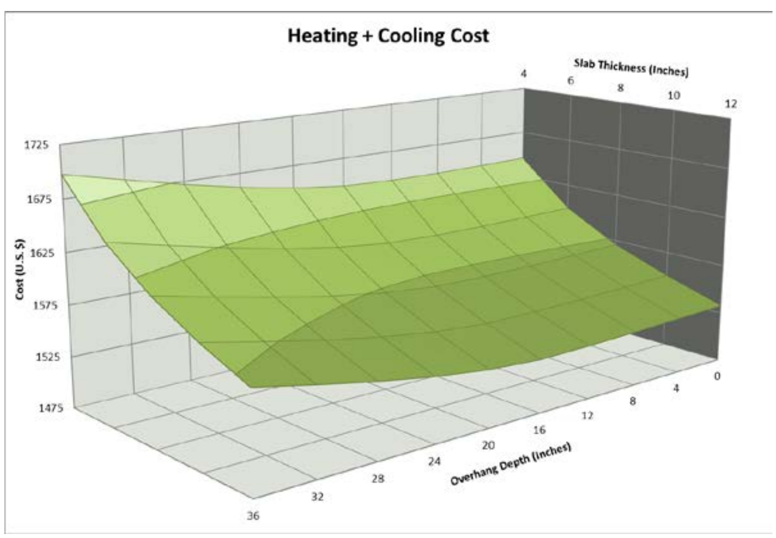


Figure 28: Energy Star Colonial Conditioning Cost With WWR=26



The Optimal design for the Energy Star Colonial faces due South, has a WWR of 26 percent, a 12” concrete slab, and a 16” window overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 29: Energy Star Colonial Baseline Design Daily Internal Gains

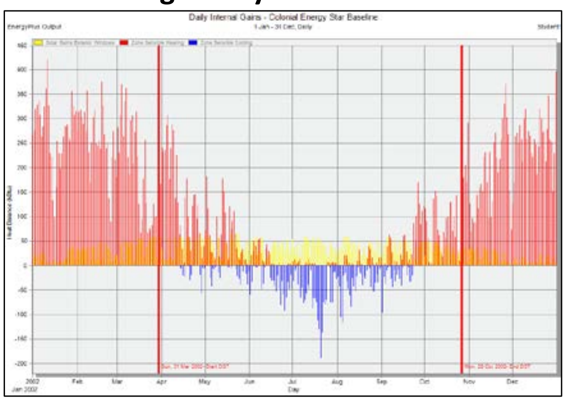


Figure 30: Energy Star Colonial Optimal Design Daily Internal Gains

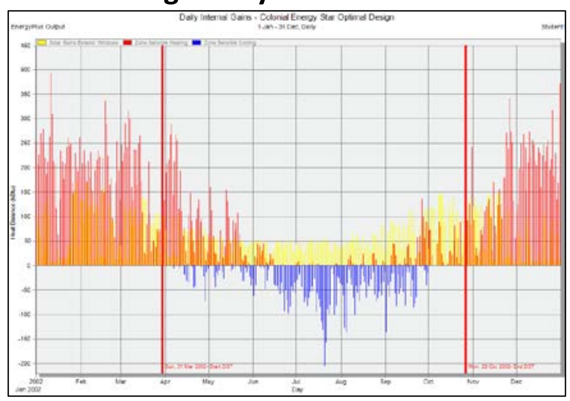


Figure 31: Energy Star Colonial Baseline Design Monthly Internal Gains

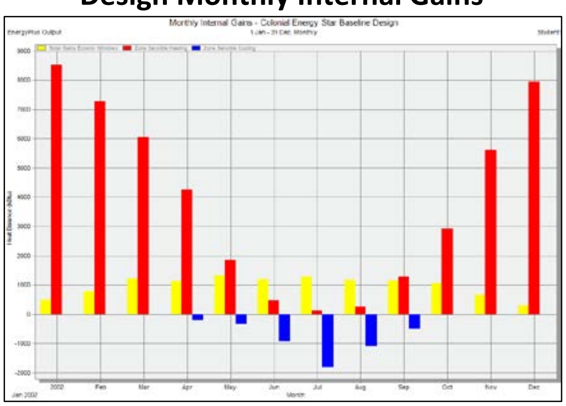


Figure 32: Energy Star Colonial Optimal Design Monthly Internal Gains

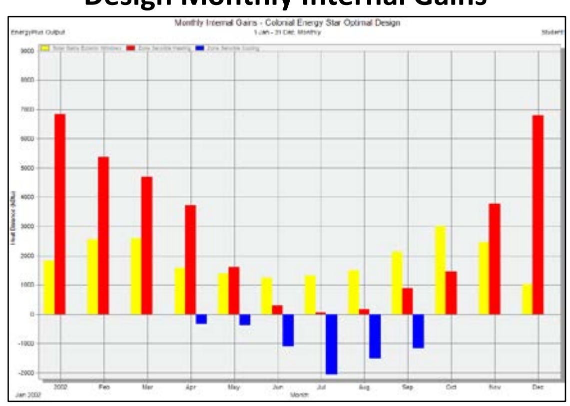


Figure 33: Energy Star Colonial Baseline Design Annual Internal Gains

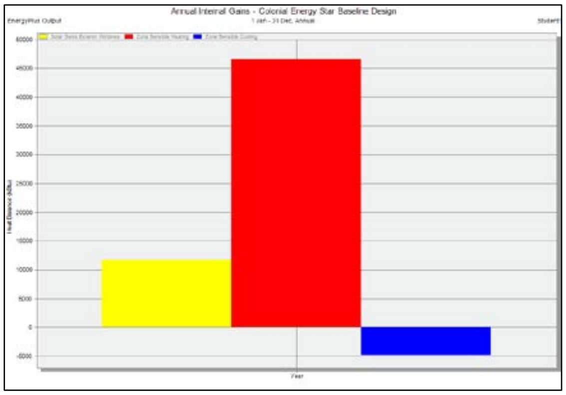


Figure 34: Energy Star Colonial Optimal Design Annual Internal Gains

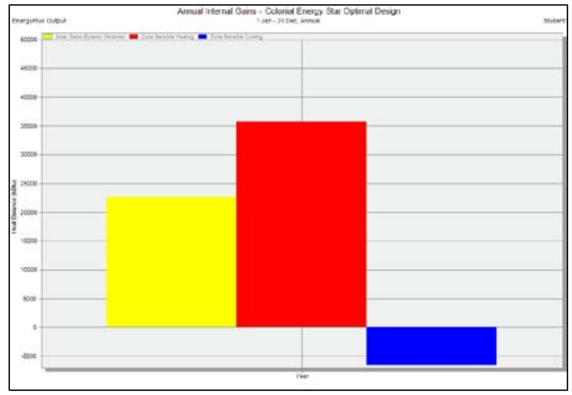


Table 8: Energy Star Colonial Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	46,597,000 BTU	-10,915,000 BTU	Annual Heating Load	35,682,000 BTU
Annual Heating Cost	$1,726	-$404	Annual Heating Cost	$1,322
Annual Cooling Load	1,789 kWh	+520 kWh	Annual Cooling Load	2,309 kWh
Annual Cooling Cost	$110	+$32	Annual Cooling Cost	$142
Total Conditioning Cost	**$1,836**	**-$372 (20.2%)**	**Total Conditioning Cost**	**$1464**

By implementing passive solar design into the Energy Star Colonial, the annual heating load was reduced by 10.9 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $404 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 520 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $32 increase of annual cooling costs. This resulted in a net reduction of $372 (20%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 35: Energy Star Colonial Baseline Design Daily Temperatures Without Mechanical Systems

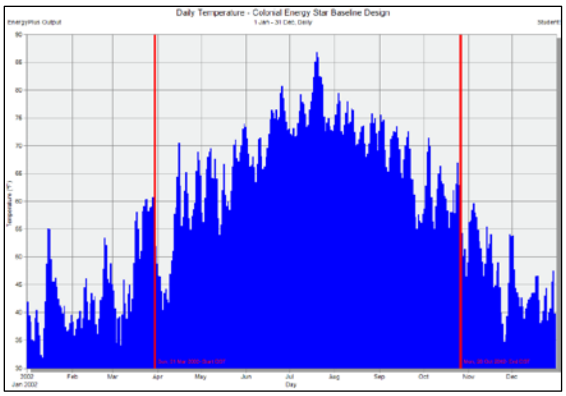


Figure 36: Energy Star Colonial Optimal Design Daily Temperatures Without Mechanical Systems

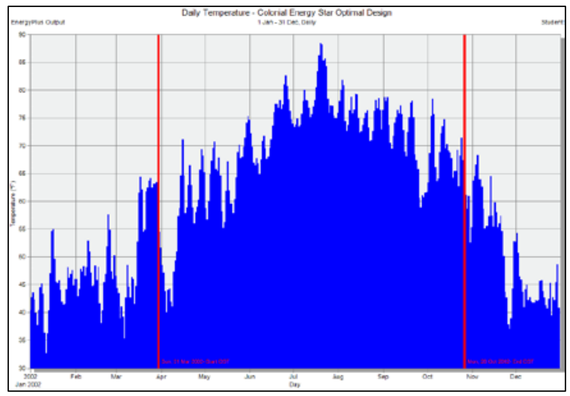


Figure 37: Energy Star Colonial Baseline Design Monthly Temperatures Without Mechanical Systems

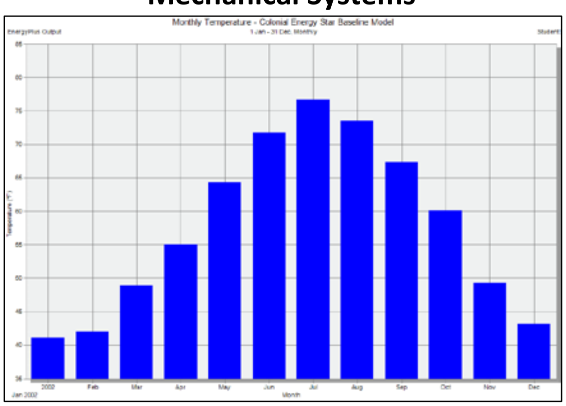
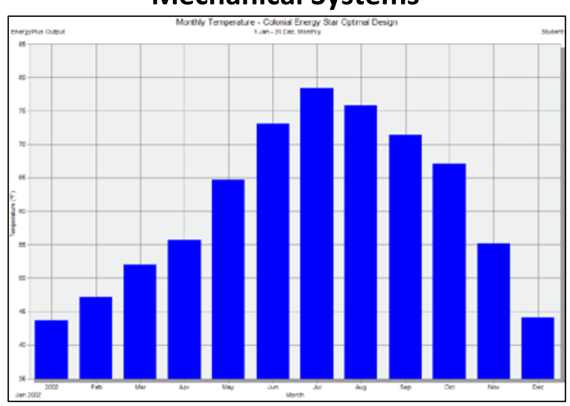


Figure 38: Energy Star Colonial Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 4-6° warmer than the baseline design. Additionally, they moderate many of the daily temperature dips, below 45°.

3.1.3 Energy Star-Passive House Colonial

The effects of orientation on the Energy Star model are quite similar to that of the IECC and Energy Star models. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling. 0° is a close second for cooling as a result of the roof oerhang over the second floor windows.

Figure 39: Energy Star-Passive House Colonial Orientation Effect on Heating Load

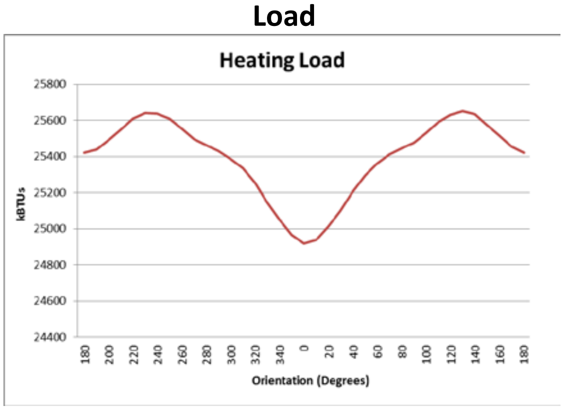
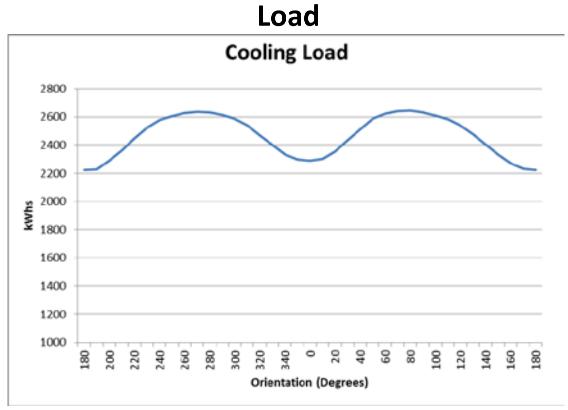


Figure 40: Energy Star-Passive House Colonial Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation

Figure 41:Energy Star-Passive House Colonial Orientation Effect on Conditioning Cost

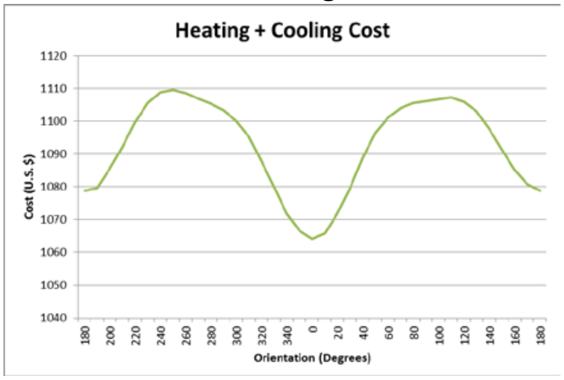
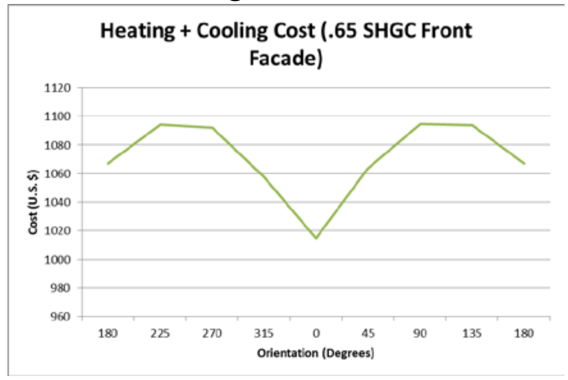


Figure 42:Energy Star-Passive House Colonial Orientation Effect on Conditioning Cost with .65 SGHC



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from $1,106 to $1014, a savings of $92 (8.3%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design.)

Figure 43: Energy Star Passive House Heating Loads with WWR = 26

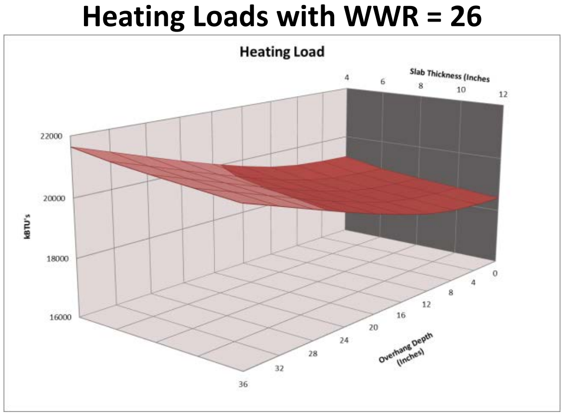


Figure 44:Energy Star Passive House Cooling Loads with WWR = 26

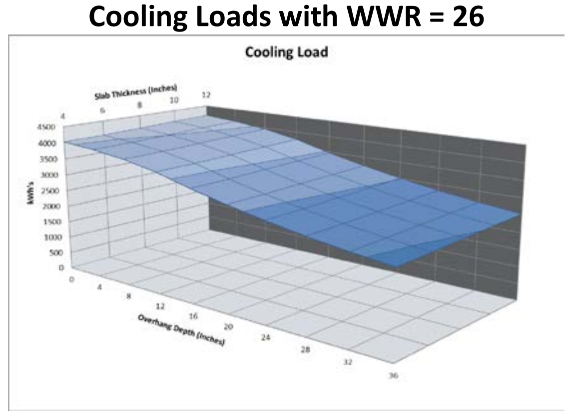
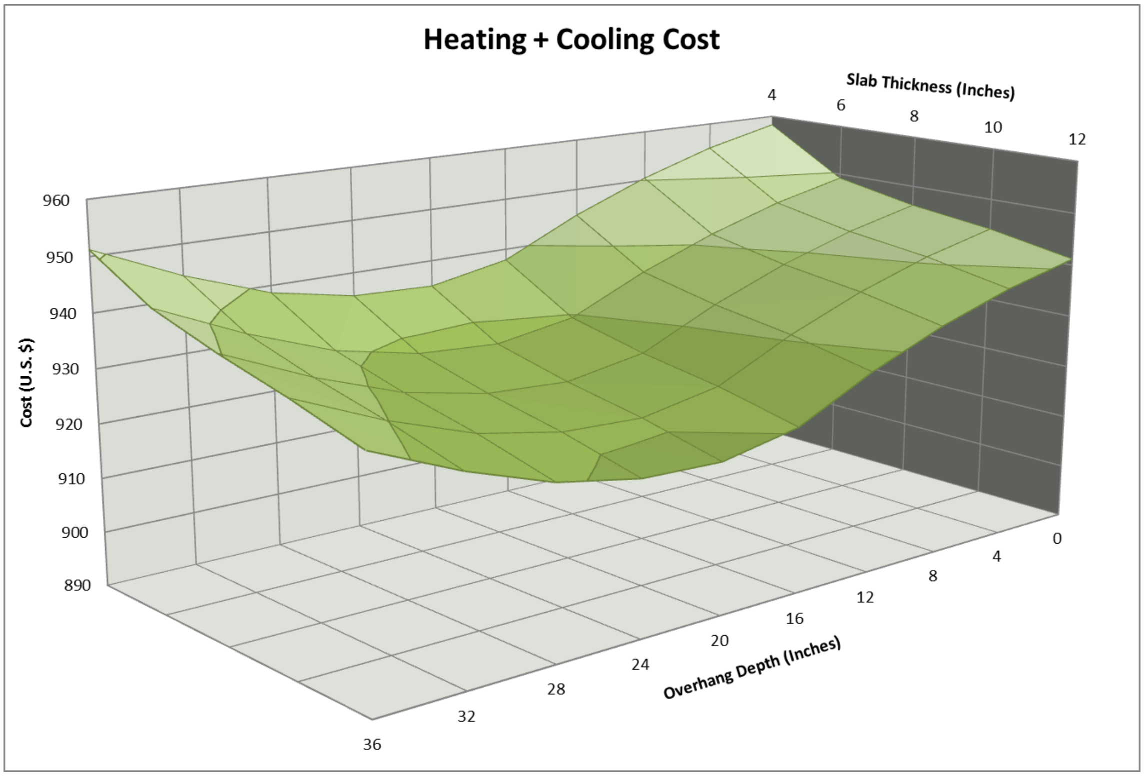


Figure 45: Energy Star Passive House Colonial Conditioning Costs with WWR = 26



The Optimal design for the Energy Star-Passive House Average Colonial faces due south, has a WWR of 26 percent, a 12” concrete slab, and a 20” window overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 46: Energy Star Passive House Colonial Baseline Design Daily Internal Gains

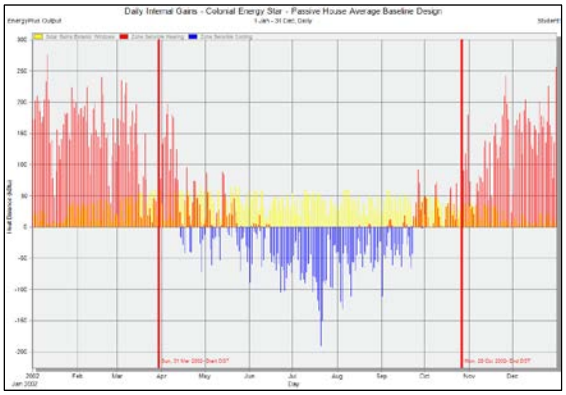


Figure 47: Energy Star Passive House Colonial Optimal Design Daily Internal Gains

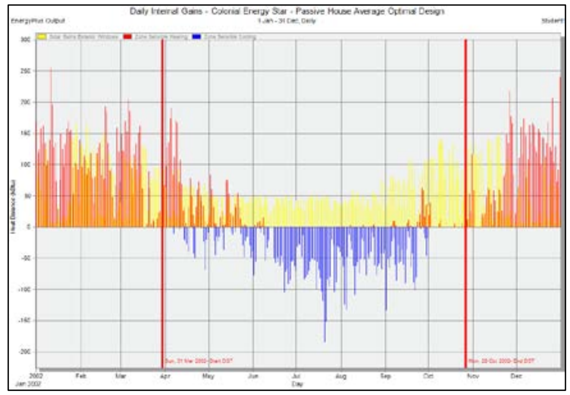


Figure 48: Energy Star Passive House Colonial Baseline Design Monthly Internal Gains

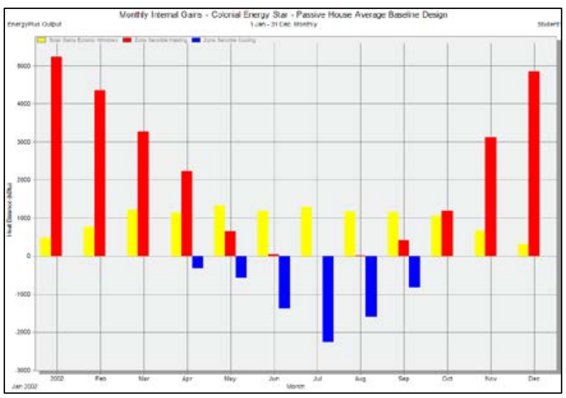


Figure 49: Energy Star Passive House Colonial Optimal Design Monthly Internal Gains

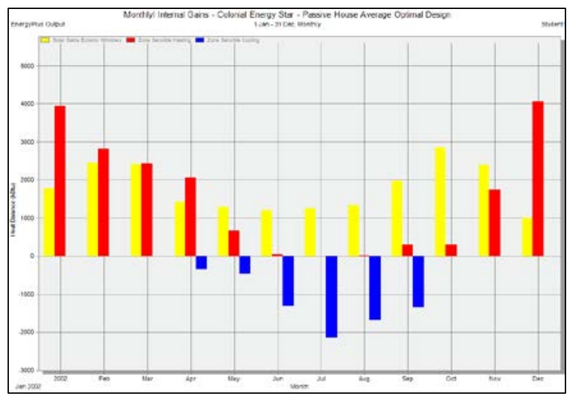


Figure 50: Energy Star Passive House Colonial Baseline Design Annual Internal Gains

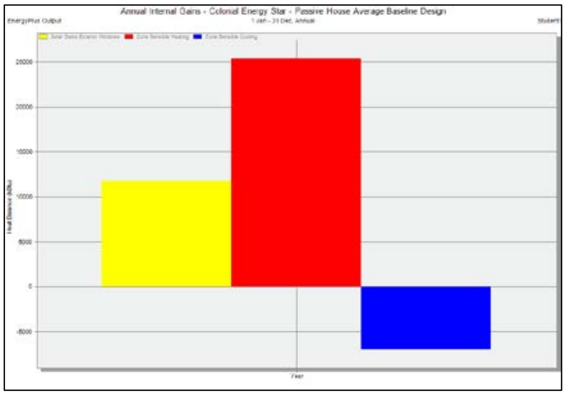


Figure 51:Energy Star Passive House Colonial Optimal Design Monthly Annual Gains

Table 9: Energy Star Passive House Colonial Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	25,349,000 BTU	-7,012,000 BTU	Annual Heating Load	18,337,000 BTU
Annual Heating Cost	$939	-$260 (27%	Annual Heating Cost	$679
Annual Cooling Load	2,429 kWh	+116 kWh	Annual Cooling Load	2,545 kWh
Annual Cooling Cost	$149	+$7(5%)	Annual Cooling Cost	$156
Total Conditioning Cost	**$1,088**	**-$253 (23.2%)**	**Total Conditioning Cost**	**$835**

By implementing passive solar design into the Energy Star-Passive House Average Colonial, the annual heating load was reduced by 7 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $260 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 116 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $7 increase of annual cooling costs. This resulted in a net reduction of $253 (23%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 52: Energy Star Passive House Colonial Baseline Design Daily Temperatures Without Mechanical Systems

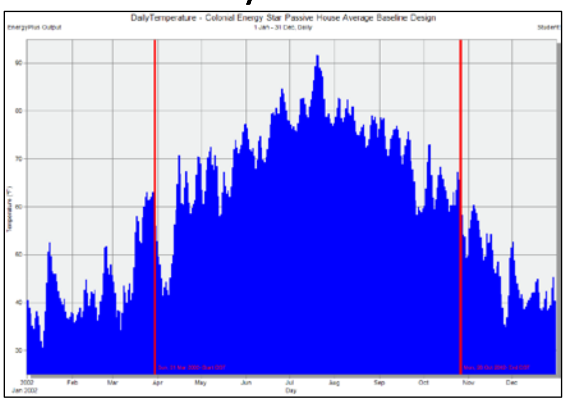


Figure 53: Energy Star Passive House Colonial Optimal Design Daily Temperatures Without Mechanical Systems

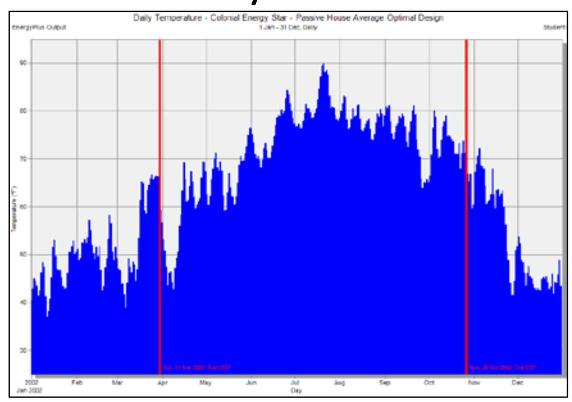


Figure 54: Energy Star Passive House Colonial Baseline Design Monthly Temperatures Without Mechanical Systems

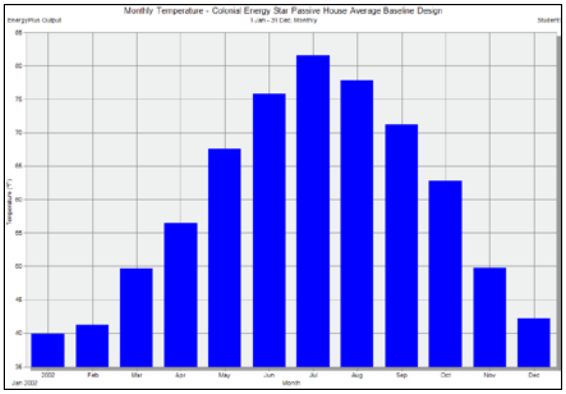
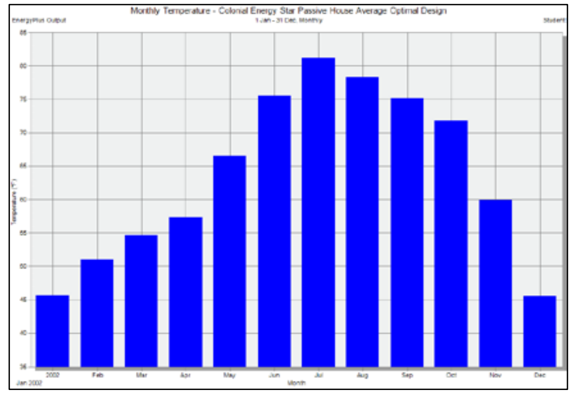


Figure 55: Energy Star Passive House Colonial Optimal Design Daily Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 6-10° warmer than the baseline design. Additionally, they moderate many of the daily temperature dips, below 45°.

3.1.4 Passive House Colonial

The effects of orientation on the Passive House model are quite similar to that of the other models. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling. Once again 0° is a close second for cooling as a result of the roof oerhang over the second floor windows.

Figure 56: Passive House Colonial Orientation Effect on Heating Load

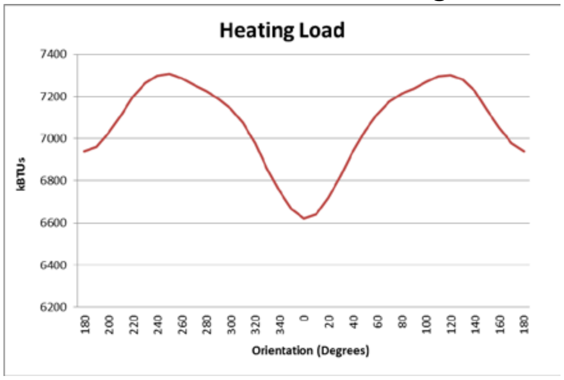
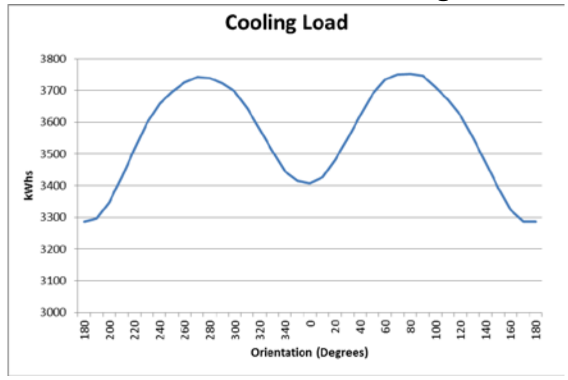


Figure 57: Passive House Colonial Orientation Effect on Heating Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation. However, given the reduced need for heating in the Passive House model, the cost is more influenced by the cooling loads than the heating loads

Figure 58: Passive House Colonial Orientation Effect on Conditioning Cost

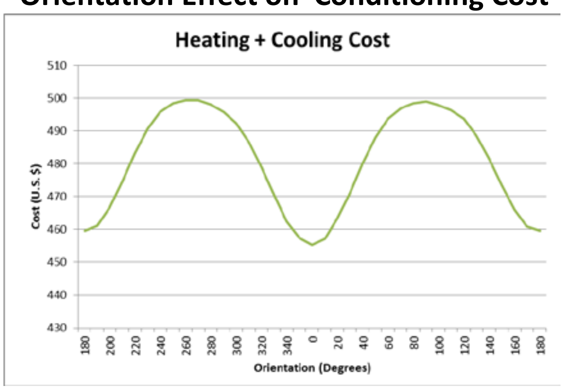
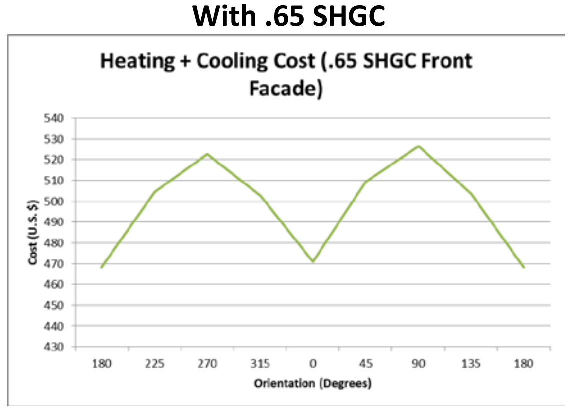


Figure 59: Passive House Colonial Orientation Effect on Conditioning Cost With .65 SHGC



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated. Given the increased importance of the cooling load for this model, the costs are actually slightly lower when the front façade is facing north ($2 less than when facing south). However, because this is a function of the cooling load, which is a largely a result of uncontrolled solar gains, once shading devices are added, facing due south becomes the optimal orientation.

By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from $498 to $470, a savings of $28 (5.6%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design.)

Figure 60: Passive House Colonial Heating Loads with WWR=23.3

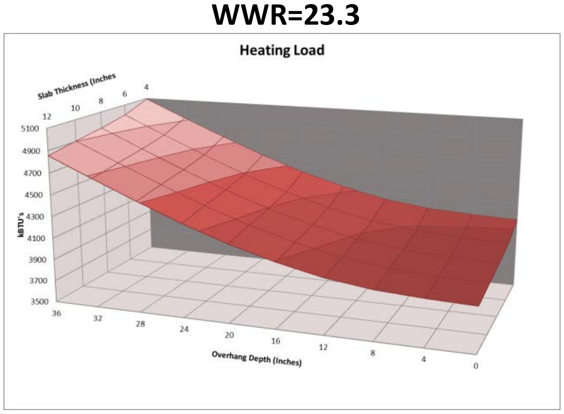


Figure 61: Passive House Colonial Heating Loads with WWR=23.3

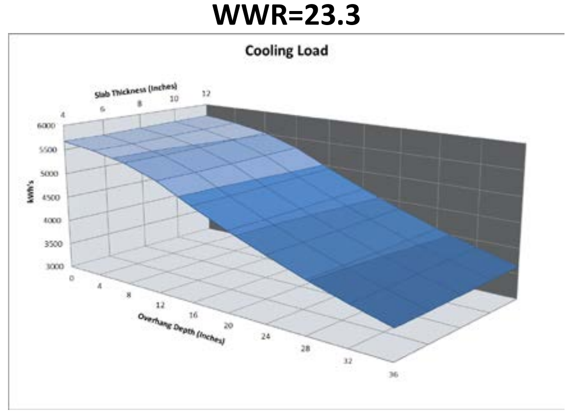
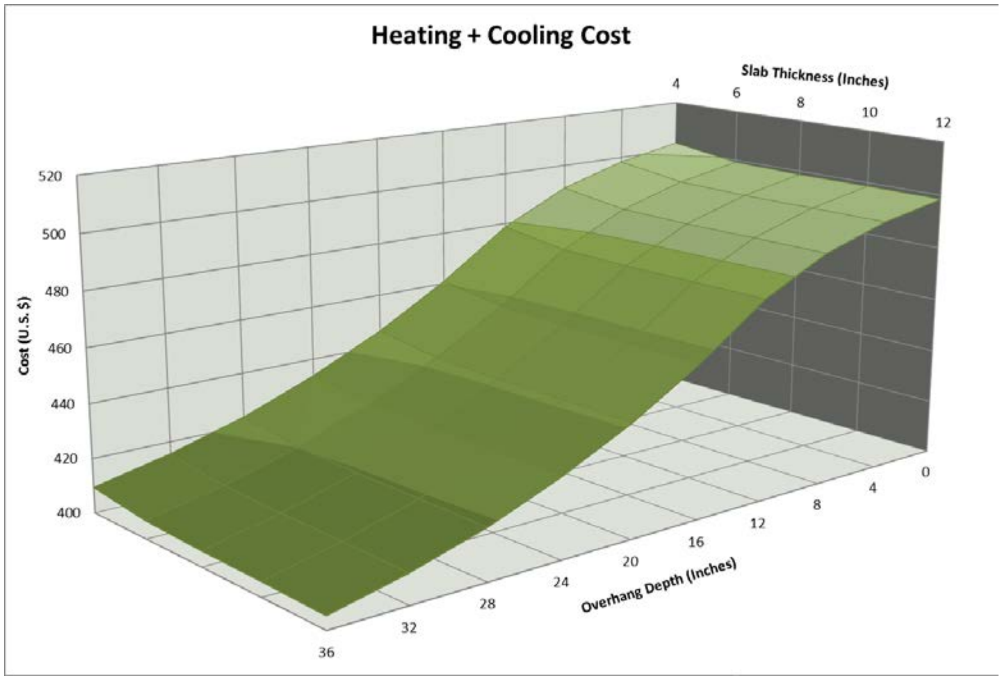


Figure 62: Passive House Colonial Conditioning Costs with WWR = 23.3



The Optimal design for the Passive House Colonial faces due South, has a WWR of 23.3 percent, a 12" concrete slab, and a 36" window overhang. The super insulated and air tight construction of the passive house model results in the heating loads being smaller than the cooling loads which are primarily a result of solar gains and various internal gains. As a result, cooling is the driving factor of the design, which is why this model doesn't reach the maximum possible WWR, and does reach the maximum shading length. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 63: Passive House Colonial Baseline Design Daily Internal Gains

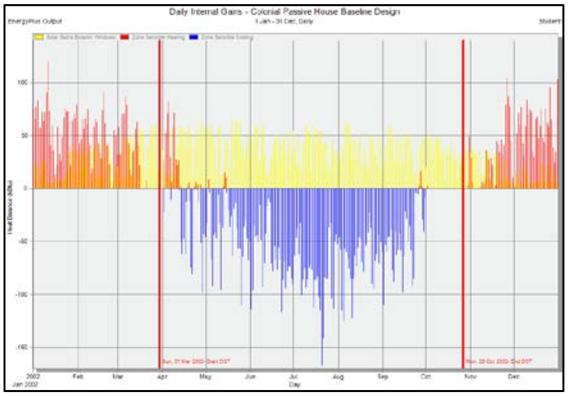


Figure 64: Passive House Colonial Optimal Design Daily Internal Gains

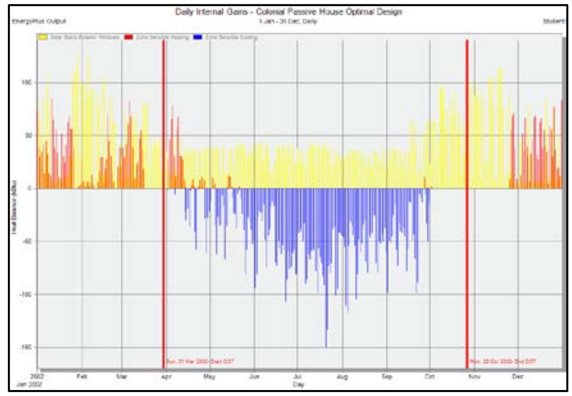


Figure 65: Passive House Colonial Baseline Design Monthly Internal Gains

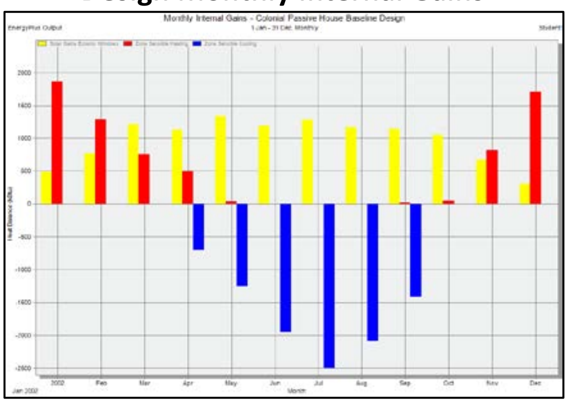


Figure 66: Passive House Colonial Optimal Design Monthly Internal Gains

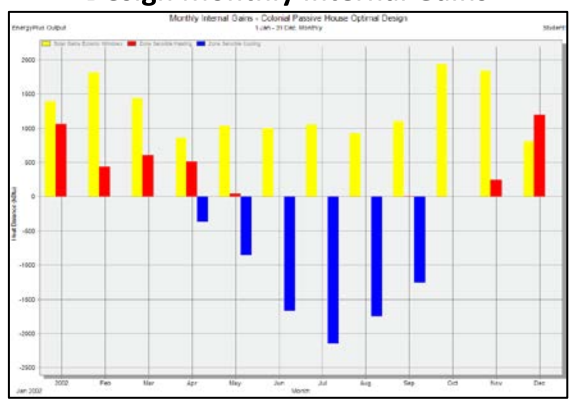


Figure 67: Passive House Colonial Baseline Design Annual Internal Gains

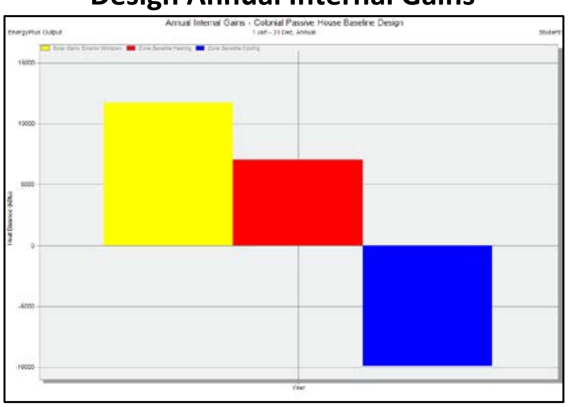


Figure 68: Passive House Colonial Optimal Design Annual Internal Gains

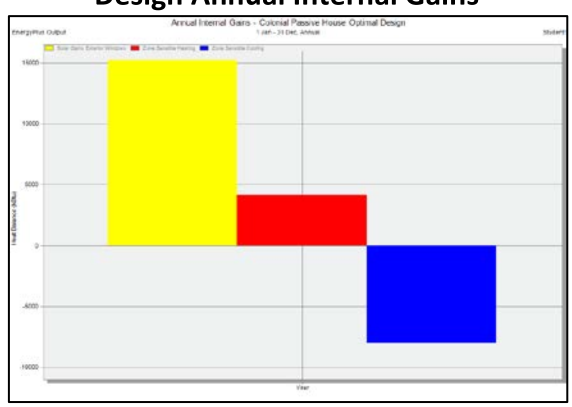


Table 10: Passive House Colonial Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	8,065,000 BTU	-3,226,000 BTU	Annual Heating Load	4,839,000 BTU
Annual Heating Cost	$299	-$120 (40%	Annual Heating Cost	$179
Annual Cooling Load	3,406 kWh	-477 kWh	Annual Cooling Load	2,929 kWh
Annual Cooling Cost	$210	-$30(14%)	Annual Cooling Cost	$180
Total Conditioning Cost	**$509**	**-$150 (29.4%)**	**Total Conditioning Cost**	**$359**

By implementing passive solar design into the Passive House Colonial, the annual heating load was reduced by 3.2 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $120 reduction of annual heating costs. Unlike the other models, the cooling was reduced. This was a result of the dramatically larger shading devices. The annual cooling was decreased by 477 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $30 decrease of annual cooling costs. This resulted in a net reduction of $150 (29%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 69: Passive House Colonial Baseline Design Daily Temperatures Without Mechanical Systems

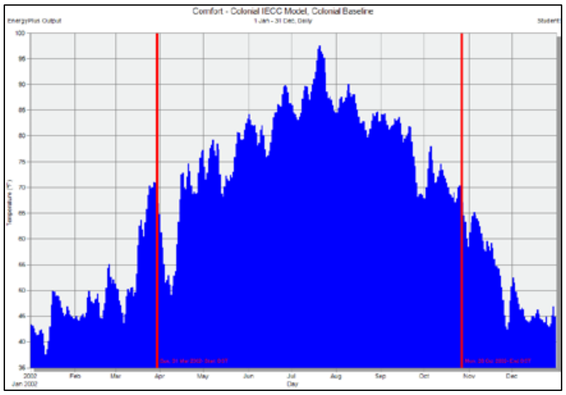


Figure 70: Passive House Colonial Optimal Design Daily Temperatures Without Mechanical Systems

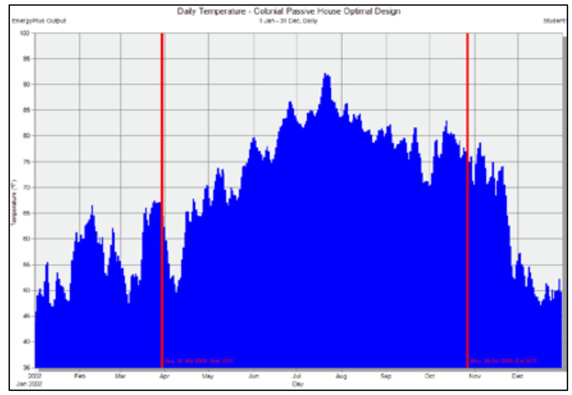


Figure 71: Passive House Colonial Baseline Design Monthly Temperatures Without Mechanical Systems

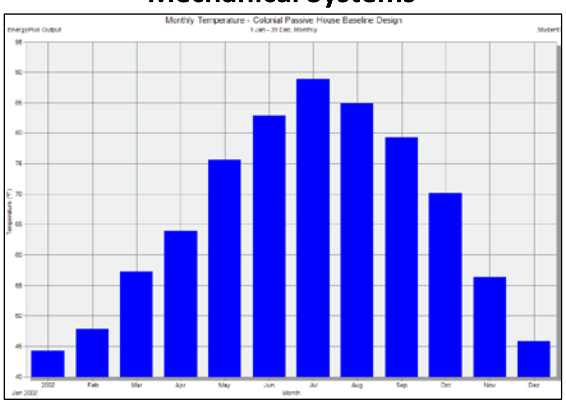
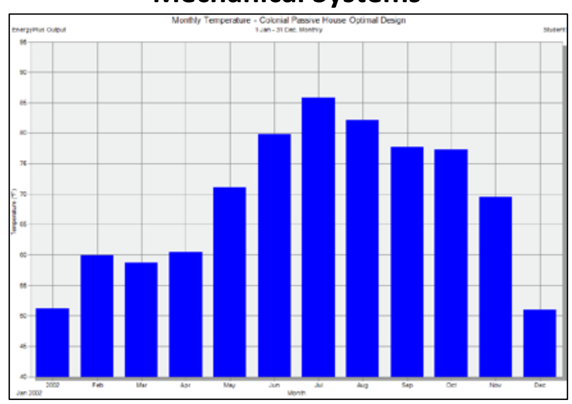


Figure 72: Passive House Colonial Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 6-13° warmer than the baseline design during the cooling season. Additionally, they moderate many of the daily temperature dips below 50°

3.2 Saltbox

Figure 73: Saltbox House

3.2.1 IECC 2009 Saltbox

In order to observe the effect of orientation on the baseline design, the model was rotated 360° at 10° increments. For these rotations, 0° indicates the front façade is facing due South, 90° indicates facing due West, 180° indicates facing due North, and 270° indicates facing due East. As these figures show, the heating load is at its maximum when the front façade, which has the highest percentage of glazing, is facing North. The heating load is minimized when the front is facing due South. Conversly, the cooling load is minimized when the front is facing North, and maximised when it is facing West. Facing South also minimizes the cooling load. This is because the existing 1’ overhang of the roof provides some shading to the second floor windows when facing south.

Figure 74: IECC 2009 Colonial Orientation Effect on Heating Load

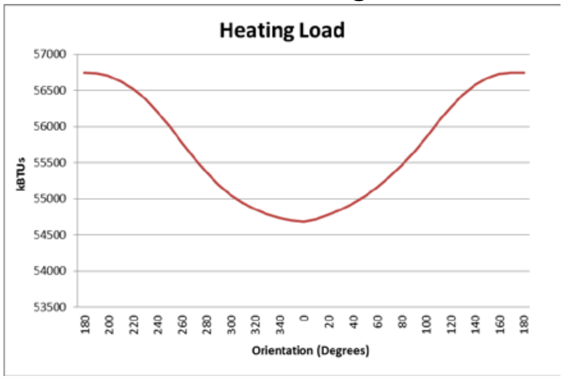
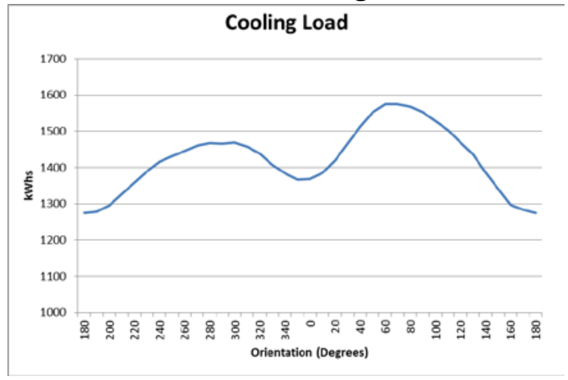


Figure 75: IECC 2009 Colonial Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation. Once it has been established that the optimal orientation is for the front façade to face due south, the appropriate solar heat gain coeffection of .65 can be applied to these windows. With these windows in place, the model is once again rotated, this time at 45° increments.

Figure 76: IECC 2009 Colonial Orientation Effect on Conditioning Cost

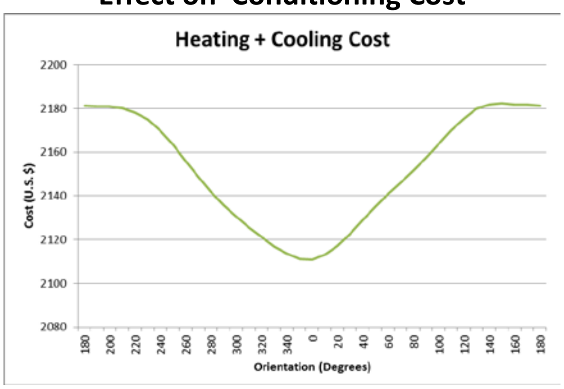
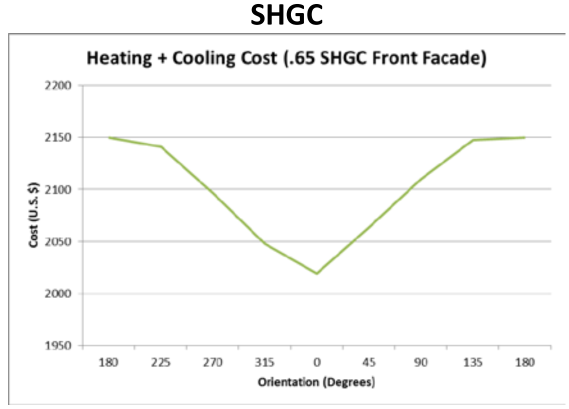


Figure 77: IECC 2009 Colonial Orientation Effect on Conditioning Cost with .65 SHGC



Once again, facing due South is the optimal orientation. By rotating the building from facing West to facing South, and using a SHGC of .65 on the Southern façade, the cost has been reduced from $2,157 to $2,019, an annual savings of $138 (6.4%)

With the building at its optimal orientation of 0°, the effect of additional southern glazing, thermal mass, and the addition of shading in the form of window overhangs, can be added. The following figures illustrate the heating load, cooling load, and total cost, of every possible combination of these variables.

The combinations of these three variables are illustrated on sets of surface graphs. The graphs show the effect that the different combinations of thermal mass and overhang depth have on the heating and cooling loads as well as total annual cost. Each set of these graphs is based on an increasing amount of WWR, starting at the baseline value of 12.4 and increasing up to 26, at which point there is no room for additonal windows.(The set of graphs shown illustrate the WWR for the optimal design, in this case, WWR=23.3. The sets of graphs for the other WWRs can be found in appendix C)

Figure 78: IECC 2009 Saltbox Heating Loads with WWR=23.3

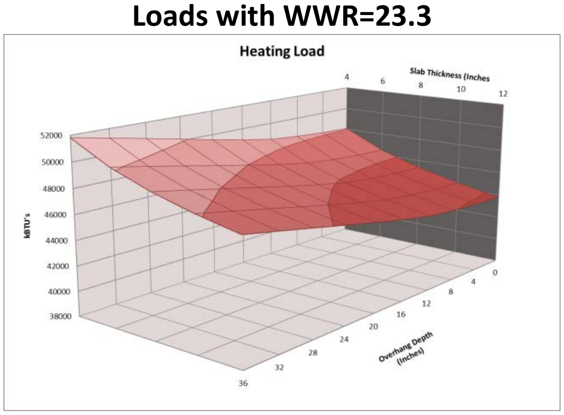


Figure 79: IECC 2009 Saltbox Cooling Loads with WWR=23.3

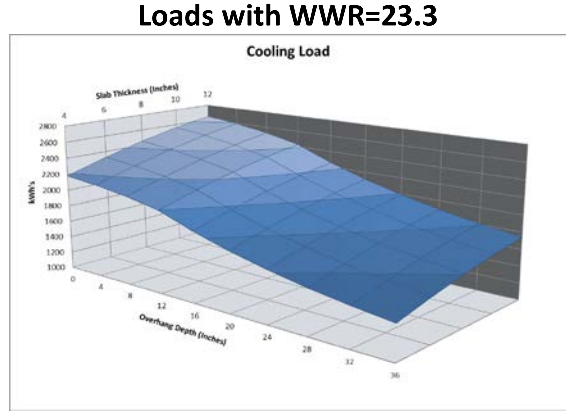
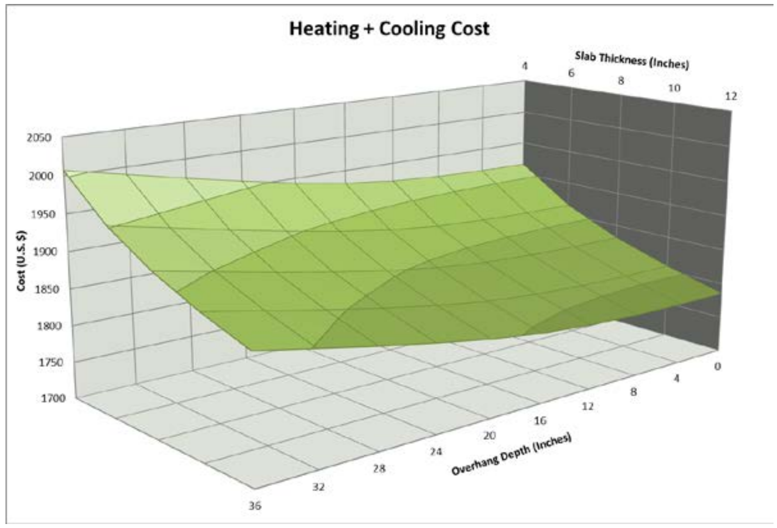


Figure 80: IECC 2009 Saltbox Conditioning Cost with WWR=23.3



The Optimal design for the IECC 2009 Saltbox faces due South, has a WWR of 23.3 percent, a 12” concrete slab, and a 0” window overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 81: IECC 2009 Saltbox Baseline Design Daily Internal Gains

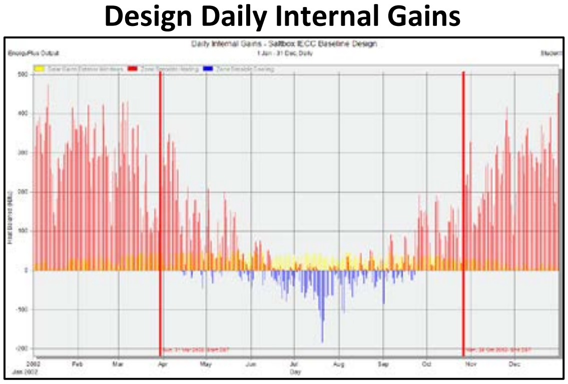


Figure 82: IECC 2009 Saltbox Optimal Design Daily Internal Gains

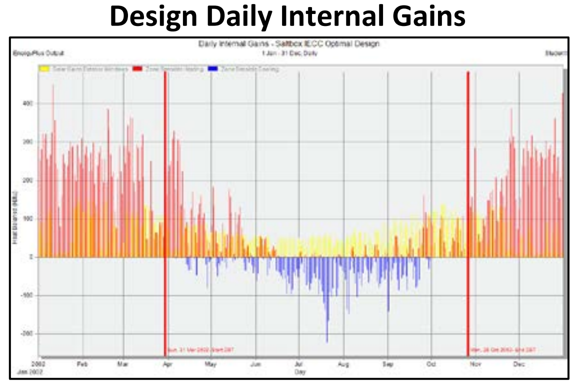


Figure 83: IECC 2009 Saltbox Baseline Design Monthly Internal Gains

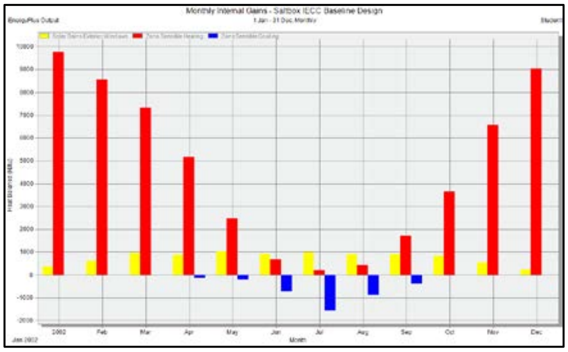


Figure 84: IECC 2009 Saltbox Optimal Design Monthly Internal Gains

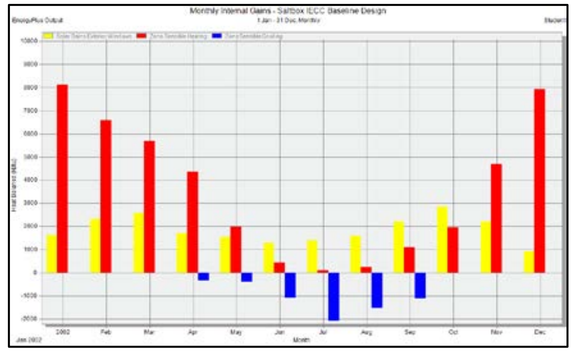


Figure 85: IECC 2009 Saltbox Baseline Design Annual Internal Gains

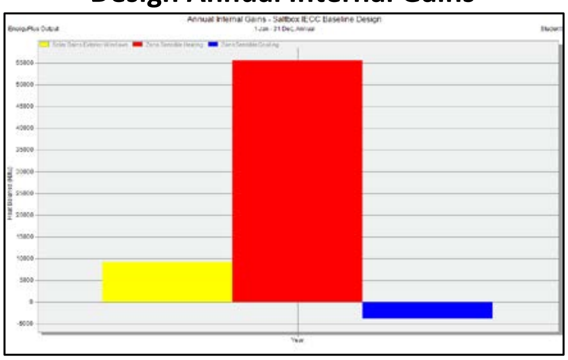


Figure 86: IECC 2009 Saltbox Optimal Design Optimal Internal Gains

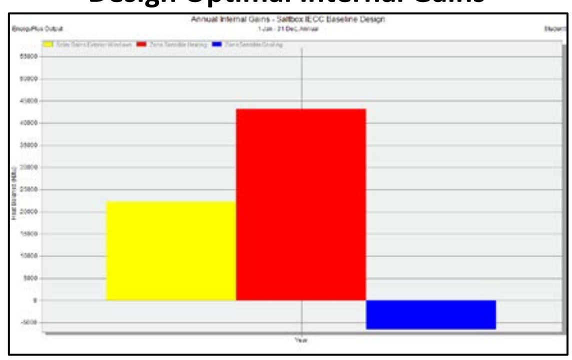


Table 11: IECC 2009 Saltbox Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	55,592,000BTU	-12,378,000 BTU	Annual Heating Load	43,214,000 BTU
Annual Heating Cost	$2059	-$458 (22.2%	Annual Heating Cost	$1601
Annual Cooling Load	1,518 kWh	+963 kWh	Annual Cooling Load	2,481 kWh
Annual Cooling Cost	$93	+$60(64%)	Annual Cooling Cost	$153
Total Conditioning Cost	**$2,152**	**-$398 (18.5%)**	**Total Conditioning Cost**	**$1,754**

By implementing passive solar design into the 2009 IECC Saltbox, the annual heating load was reduced by 12.4 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $458 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 963 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $60 increase of annual cooling costs. This resulted in a net reduction of $398 (18.5%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 87: IECC 2009 Saltbox Baseline Design Daily Temperatures Without Mechanical Systems

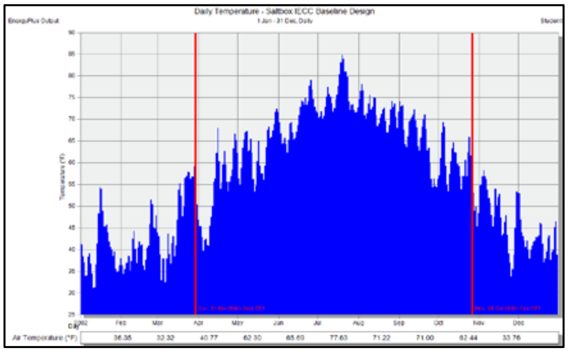


Figure 88: IECC 2009 Saltbox Optimal Design Daily Temperatures Without Mechanical Systems

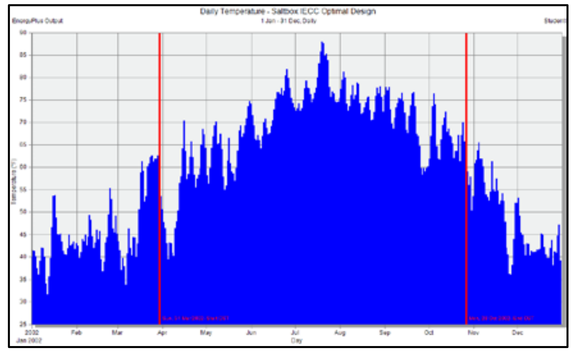


Figure 89: IECC 2009 Saltbox Baseline Design monthly Temperatures Without Mechanical Systems

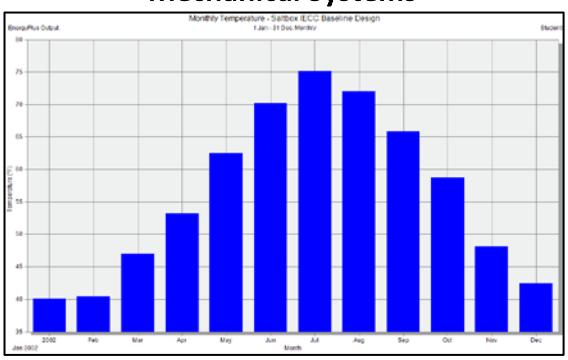
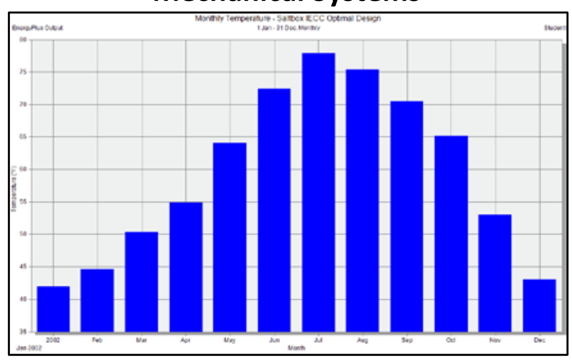


Figure 90: IECC 2009 Saltbox Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 3-5° warmer than the baseline design. Additionally, they minimize many of the daily temperature dips below 35°, especially in February and March.

3.2.2 Energy Star Saltbox

The effects of orientation on the Energy Star model are quite similar to that of the IECC model. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling. Once again 0° is a close second for cooling as a result of the roof overhang over the second floor windows.

Figure 91: Energy Star Saltbox Orientation Effect on Heating Load

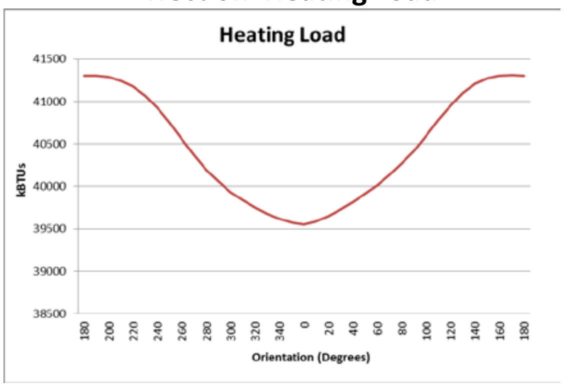
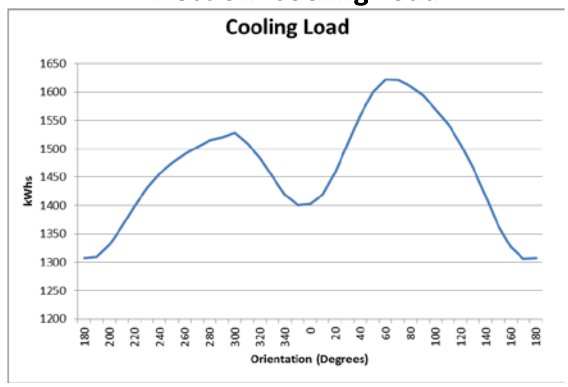


Figure 92: Energy Star Saltbox Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 93: Energy Star Saltbox Orientation Effect on Conditioning Cost

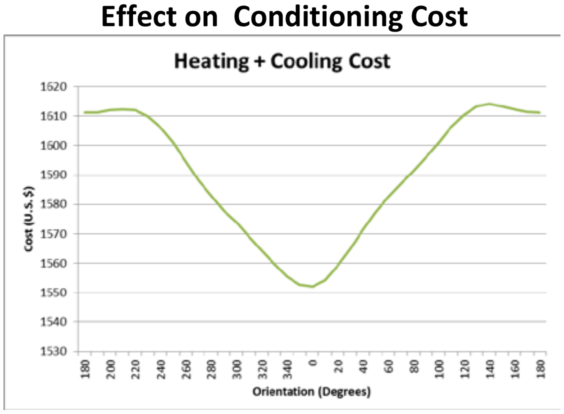
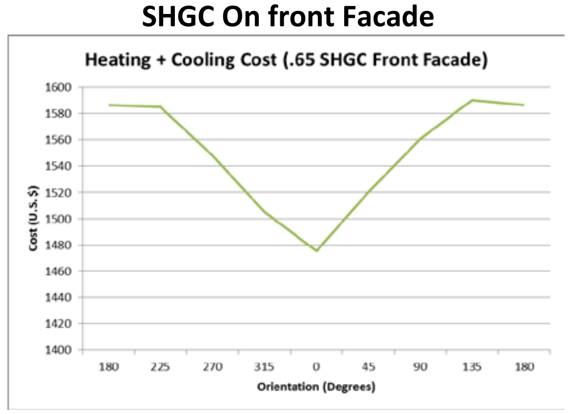


Figure 94: Energy Star Saltbox Orientation Effect on Conditioning Cost With .65 SHGC On front Facade



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from $1,595 to $1,475, a savings of $120 (7.5%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design.)

Figure 95: Energy Star Saltbox Heating Loads with WWR= 23.3

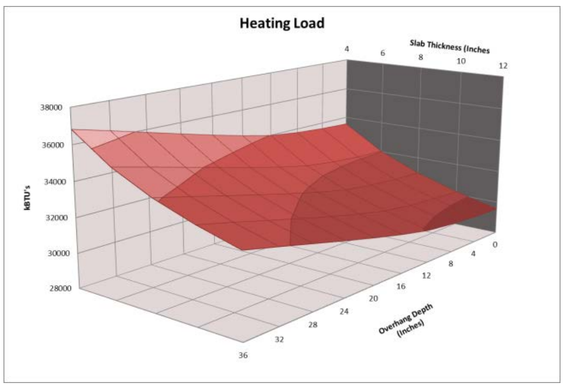


Figure 96: Energy Star Saltbox Cooling Loads with WWR= 23.3

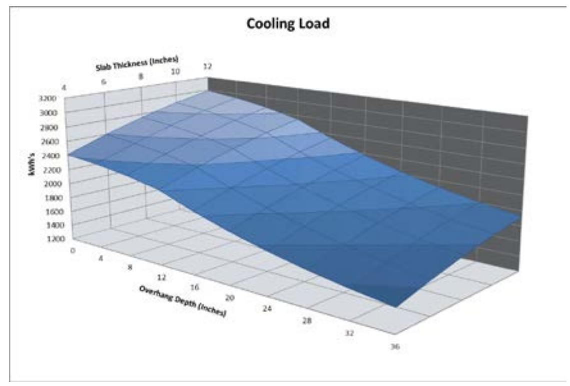
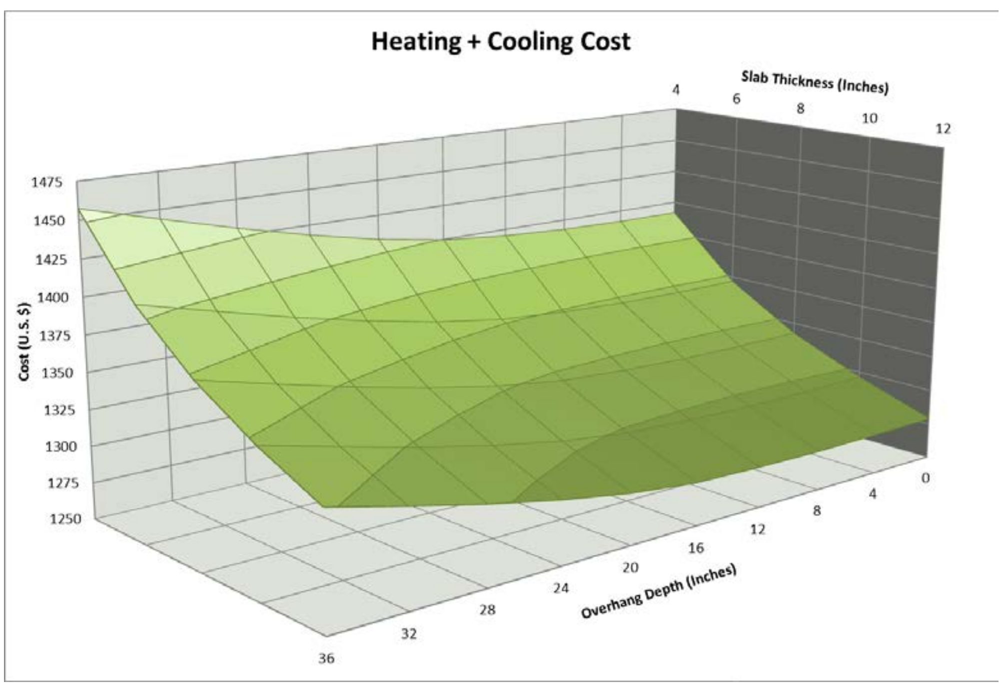


Figure 97: Energy Star Saltbox Conditioning Costs with WWR = 23.3



The Optimal design for the Energy Star Colonial faces due south, has a WWR of 23.3 percent, a 12" concrete slab, and an 8" window overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 98: Energy Star Saltbox Baseline Design Daily Internal Gains

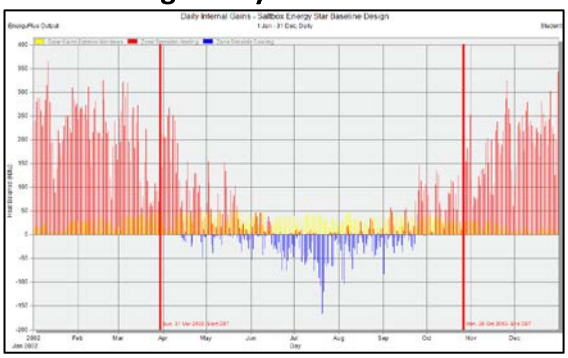


Figure 99: Energy Star Saltbox Optimal Design Daily Internal Gains

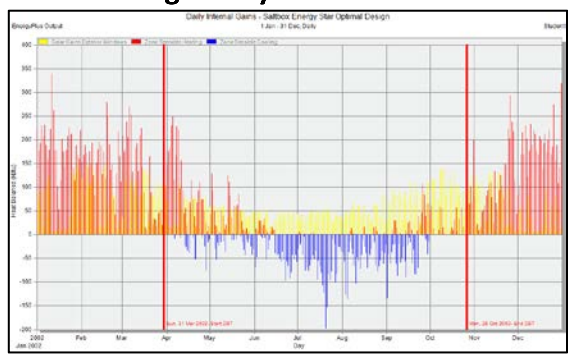


Figure 100: Energy Star Saltbox Baseline Design Monthly Internal Gains

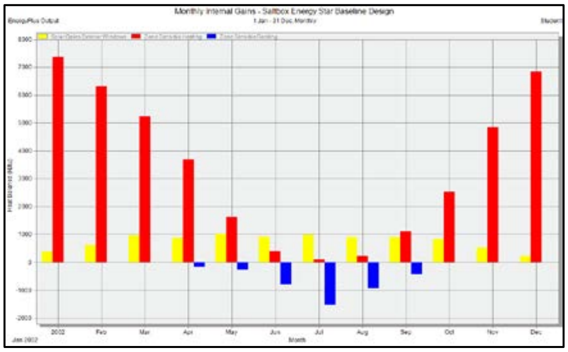


Figure 101: Energy Star Saltbox Optimal Design Monthly Internal Gains

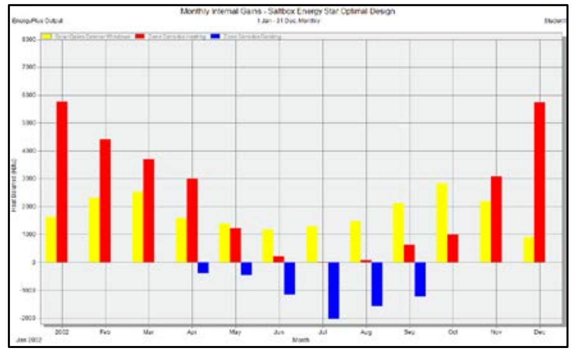


Figure 102: Energy Star Saltbox Baseline Design Annual Internal Gains

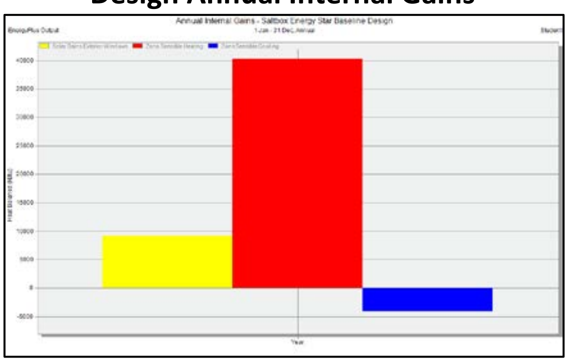


Figure 103: Energy Star Saltbox Optimal Design Annual Internal Gains

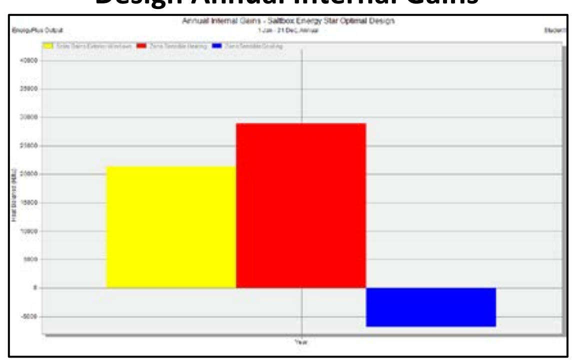


Table 12: Energy Star Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	40,342,000BTU	-11,401,000 BTU	Annual Heating Load	28,941,000 BTU
Annual Heating Cost	$1,494	-$422 (28.2%	Annual Heating Cost	$1,072
Annual Cooling Load	1,546 kWh	+949 kWh	Annual Cooling Load	2,495 kWh
Annual Cooling Cost	$95	+$59(62%)	Annual Cooling Cost	$154
Total Conditioning Cost	**$1,589**	**-$363 (22.8%)**	**Total Conditioning Cost**	**$1,226**

By implementing passive solar design into the Energy Star Saltbox, the annual heating load was reduced by 11.4 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $422 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 949 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $59 increase of annual cooling costs. This resulted in a net reduction of $363 (22.8%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 104: Figure 69: Energy Star Saltbox Baseline Design Daily Temperatures Without Mechanical Systems

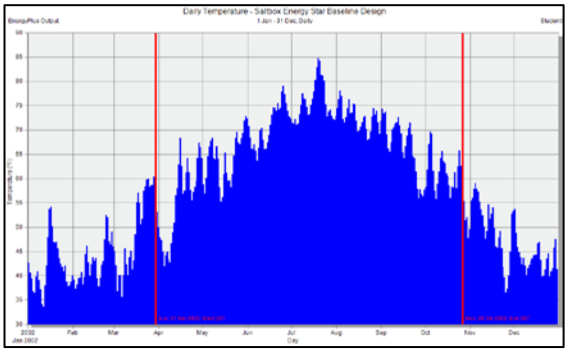


Figure 105: Figure 69: Energy Star Saltbox Optimal Design Daily Temperatures Without Mechanical Systems

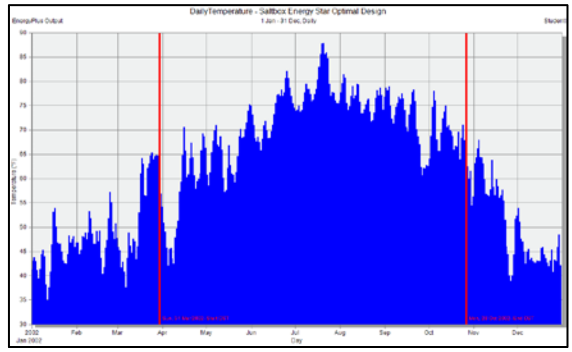


Figure 106: Figure 69: Energy Star Saltbox Baseline Design Monthly Temperatures Without Mechanical Systems

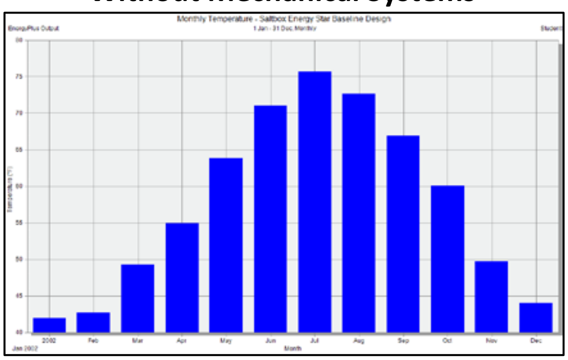
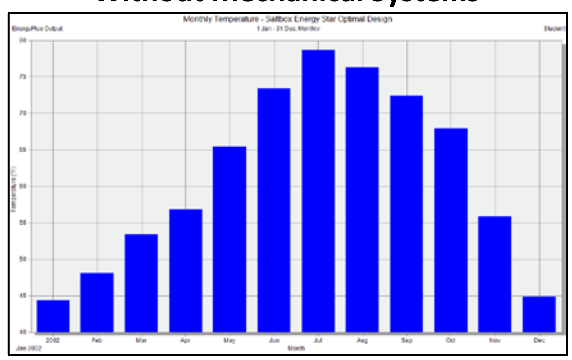


Figure 107: Figure 69: Energy Star Saltbox Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 4-6° warmer than the baseline design. Additionally, they moderate many of the daily temperature dips, below 45°.

3.2.3 Energy Star-Passive House Saltbox

The effects of orientation on the Energy Star - Passive House model are quite similar to that of the IECC and Energy Star models. O° is the optimal orientation for heating purposes, and 180° is the optimal for cooling.

Figure 108: Energy Star-Passive House Saltbox Orientation Effect on Heating Load

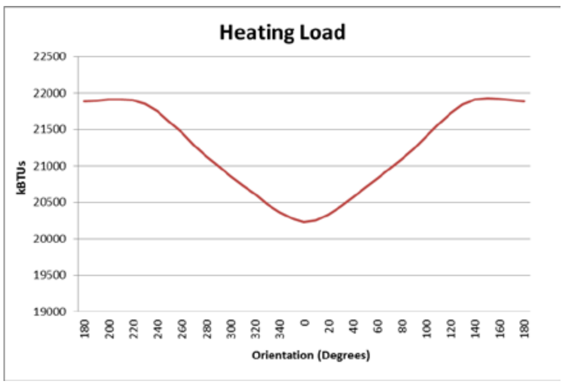
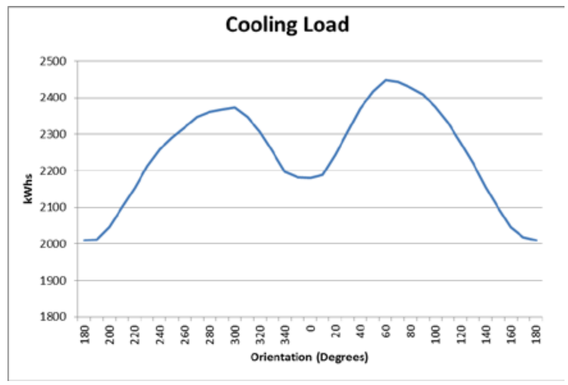


Figure 109: Energy Star-Passive House Saltbox Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 110: Energy Star-Passive House Saltbox Orientation Effect on Conditioning Cost

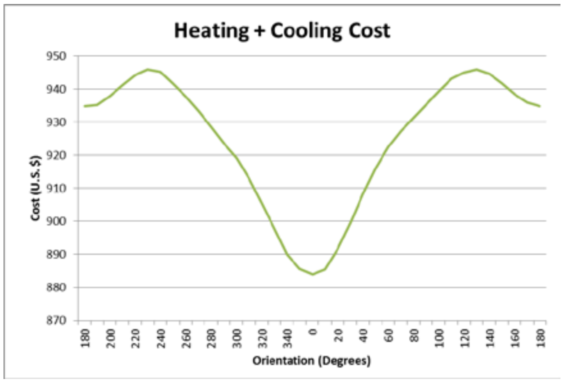
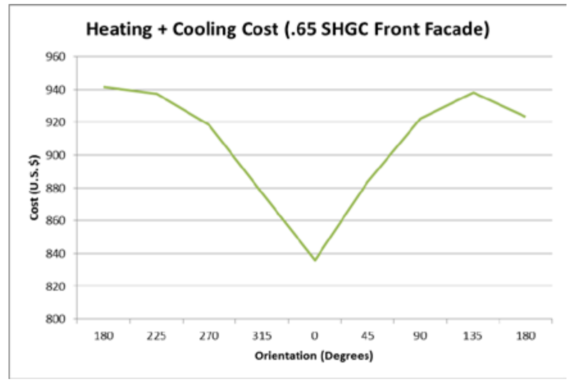


Figure 111: Energy Star-Passive House Saltbox Orientation Effect on Conditioning Cost With .65 SGHC on Front Facade



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from $935 to $836, a savings of $99 (10.5%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design.)

Figure 112: Energy Star- Passive House Saltbox Heating Loads with WWR=23.3

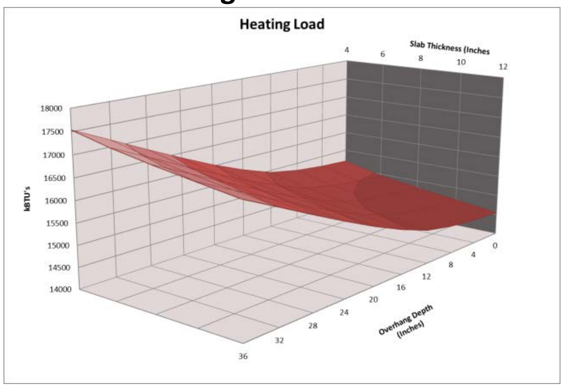


Figure 113: Energy Star- Passive House Saltbox Heating Loads with WWR=23.3

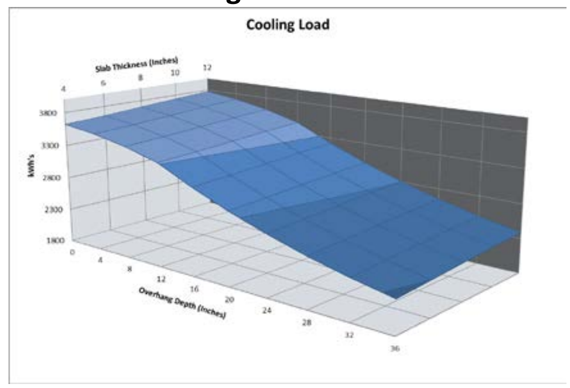
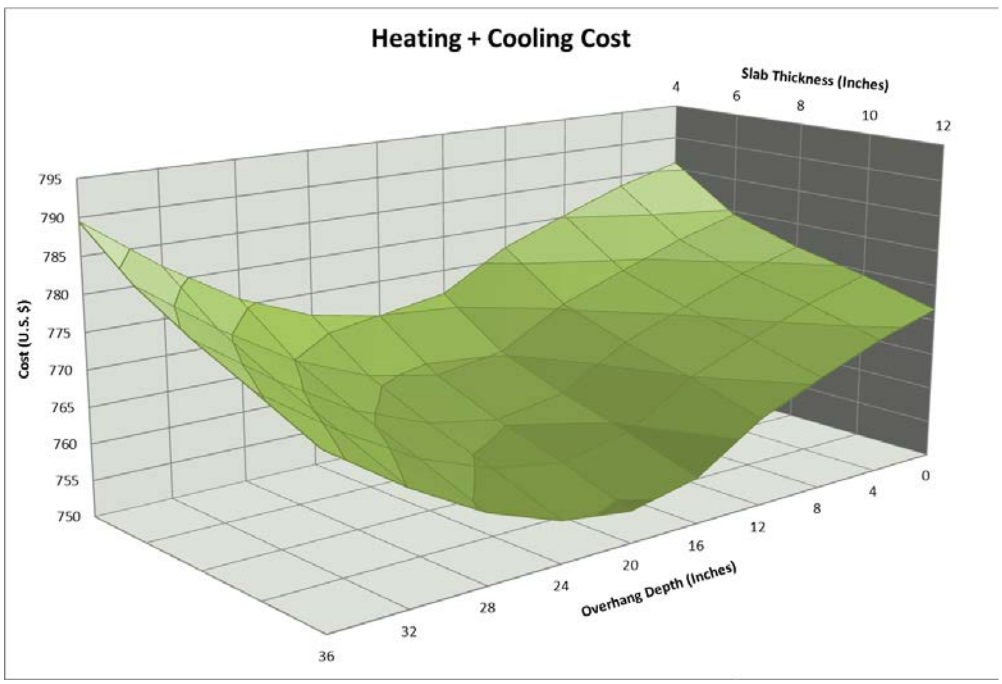


Figure 114: Energy Star Saltbox Conditioning Costs with WWR = 23.3



The Optimal design for the Energy Star-Passive House Average Saltbox faces due south, has a WWR of 23.3 percent, a 12” concrete slab, and a 20” window overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 115: Energy Star-Passive House Saltbox Baseline Design Daily Internal Gains

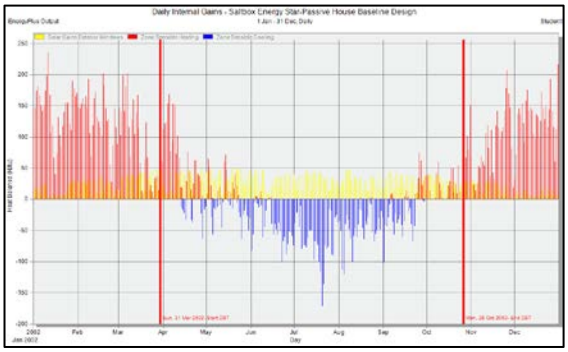


Figure 116: Energy Star-Passive House Saltbox Optimal Design Daily Internal Gains

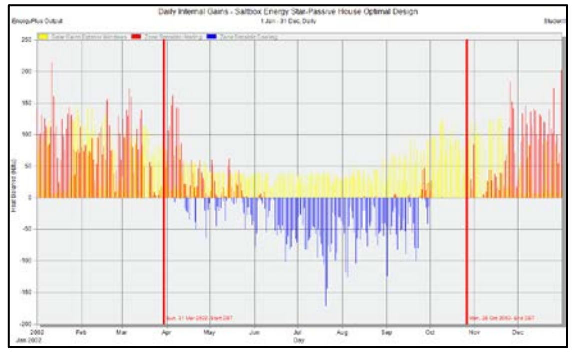


Figure 117: Energy Star-Passive House Saltbox Baseline Design Monthly Internal Gains

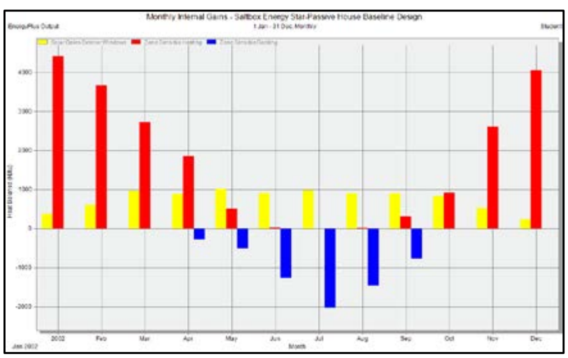


Figure 118: Energy Star-Passive House Saltbox Optimal Design Monthly Internal Gains

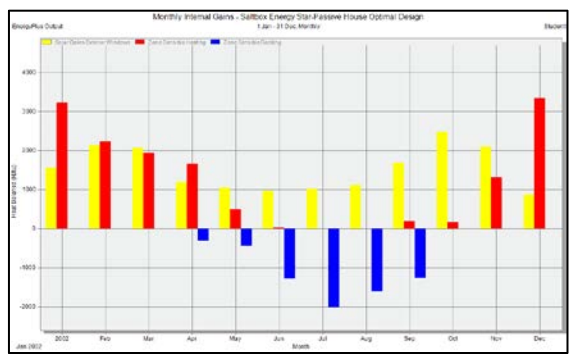


Figure 119: Energy Star-Passive House Saltbox Baseline Design Annual Internal Gains

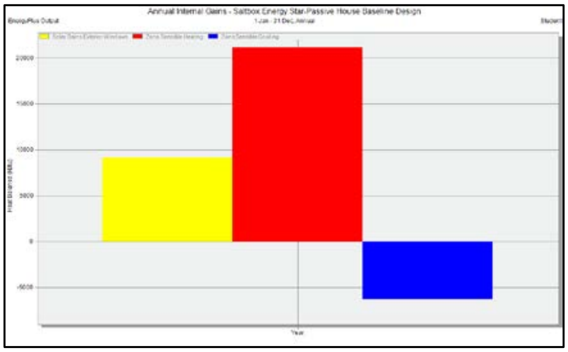


Figure 120: Energy Star-Passive House Saltbox Optiaml Design Annual Internal Gains

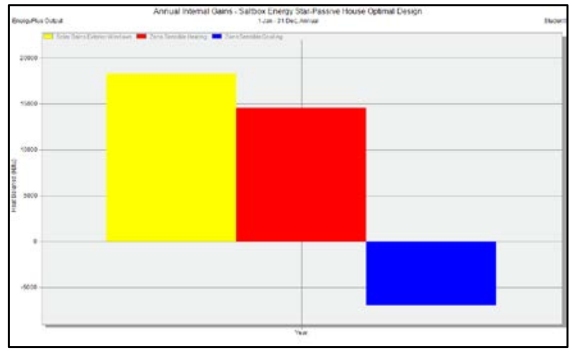


Table 13: Energy Star-Passive House Saltbox Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	21,099,000BTU	-6,522,000 BTU	Annual Heating Load	14,577,000 BTU
Annual Heating Cost	$782	-$242 (31%	Annual Heating Cost	$540
Annual Cooling Load	2,283 kWh	+248 kWh	Annual Cooling Load	2,531 kWh
Annual Cooling Cost	$141	+$15(11%)	Annual Cooling Cost	$156
Total Conditioning Cost	**$923**	**-$227 (24.6%)**	**Total Conditioning Cost**	**$696**

By implementing passive solar design into the Energy Star – Passive House Saltbox, the annual heating load was reduced by 6.5 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $242 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 248 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $15 increase of annual cooling costs. This resulted in a net reduction of $227 (24.6%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 121: Energy Star-Passive House Saltbox Baseline Design Daily Temperatures Without Mechanical Systems

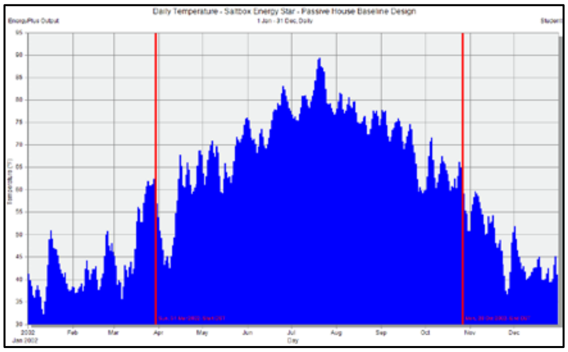


Figure 122: Energy Star-Passive House Saltbox Optimal Design Daily Temperatures Without Mechanical Systems

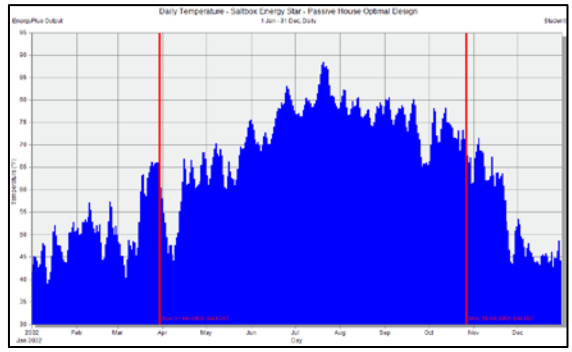


Figure 123: Energy Star-Passive House Saltbox Baseline Design Monthly Temperatures Without Mechanical Systems

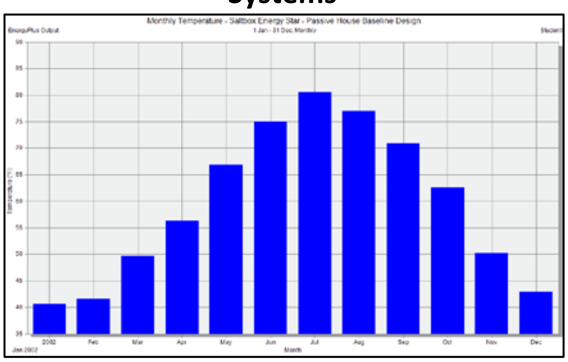
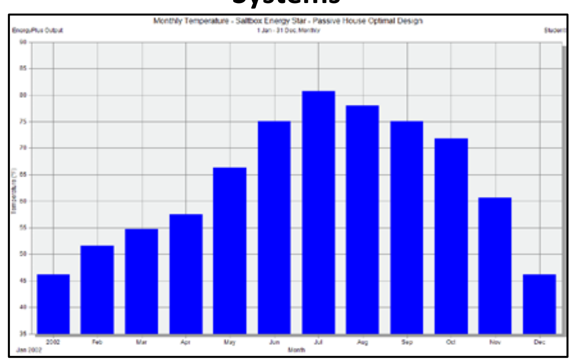


Figure 124: Energy Star-Passive House Saltbox Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 5-10° warmer than the baseline design. Additionally, they minimize many of the daily temperature dips below 45°.

3.2.4 Passive House Saltbox

The effects of orientation on the Passive House model are similar to that of the other models. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling.

Figure 125: Passive House Saltbox Orientation Effect on Heating Load

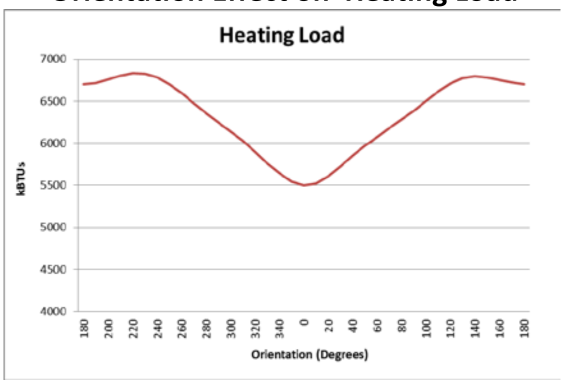
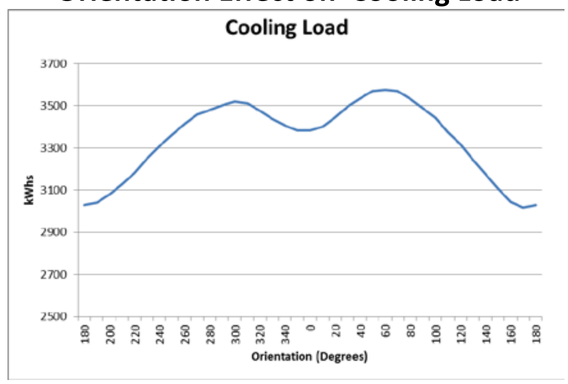


Figure 126: Passive House Saltbox Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation. However, given the reduced need for heating with the Passive House model, the cost is more influenced by the cooling loads than the heating loads.

Figure 127: Passive House Saltbox Orientation Effect on Conditioning Cost

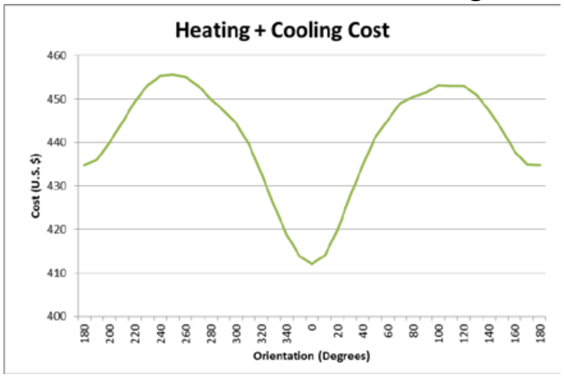
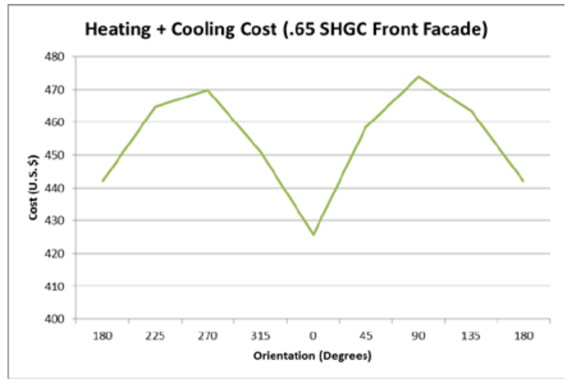


Figure 128: Passive House Colonial Orientation Effect on Conditioning Cost With .65 SHGC on Front Facade



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from \$451 to \$425, a savings of \$26 (5.7%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design)

Figure 129: Passive House Saltbox Heating Loads with WWR=20.6

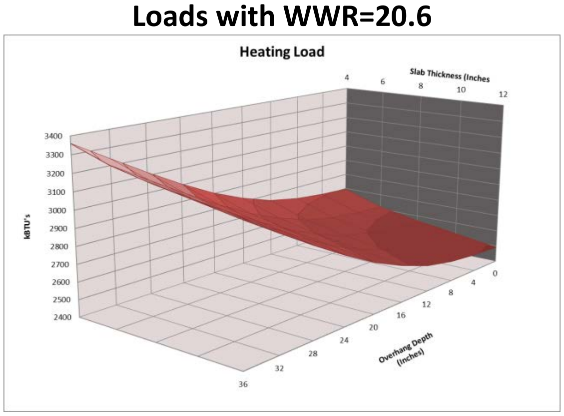


Figure 130: Passive House Saltbox Heating Loads with WWR=20.6

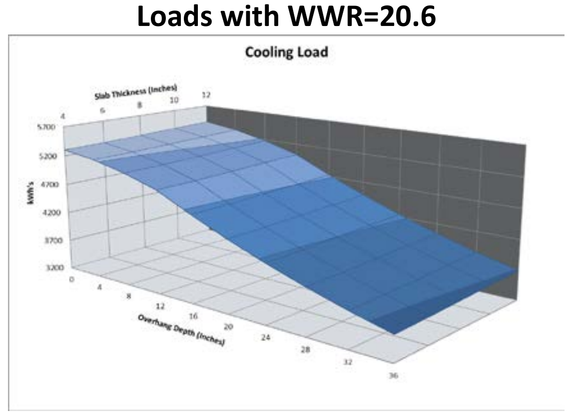
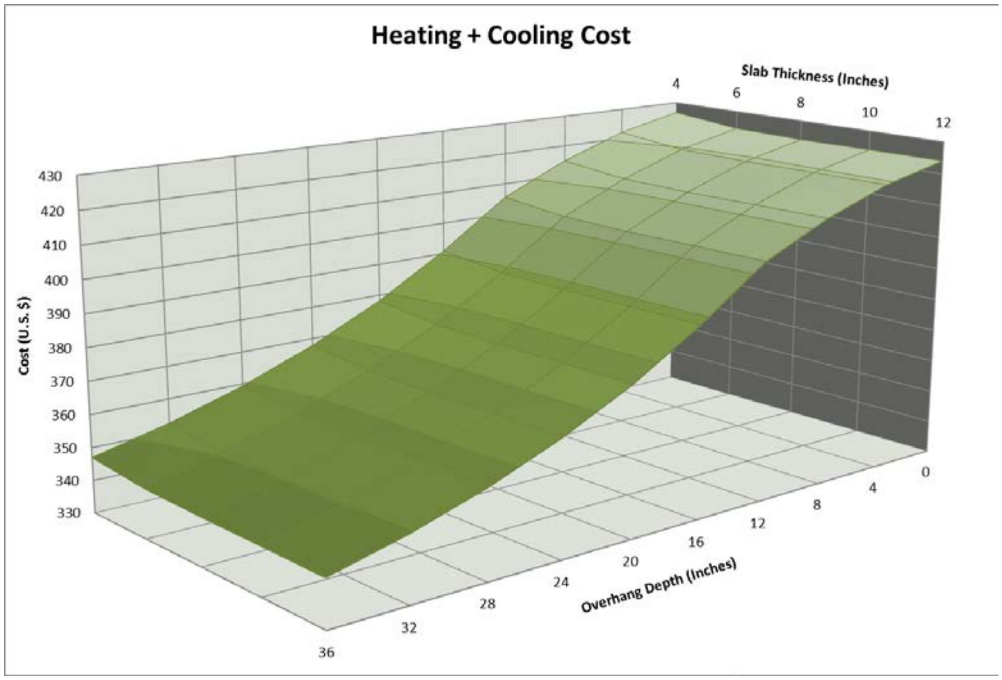


Figure 131: Passive House Saltbox Conditioning Costs with WWR = 20.6



The Optimal design for the Passive House Saltbox faces due south, has a WWR of 20.6 percent, a 12” concrete slab, and a 36” window overhang. The super insulated and air tight construction of the passive house model results in the heating loads being smaller than the cooling loads which are primarily a result of solar gains and various internal gains. As a result, cooling is the driving factor of the design, which is why this model doesn’t reach the maximum possible WWR, and does reach the maximum shading length. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 132: Passive House Saltbox Baseline Design Daily Internal Gains

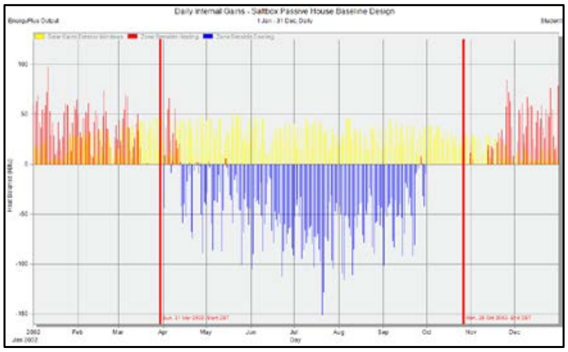


Figure 133: Passive House Saltbox Optimal Design Daily Internal Gains

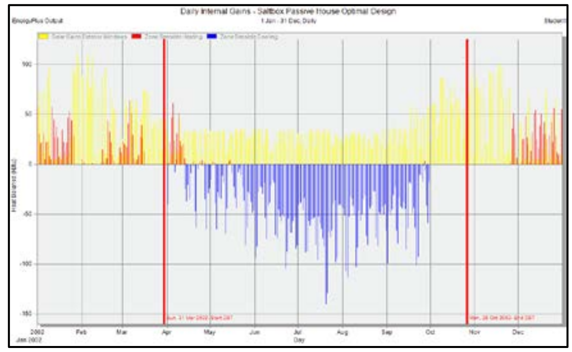


Figure 134: Passive House Saltbox Baseline Design Monthly Internal Gains

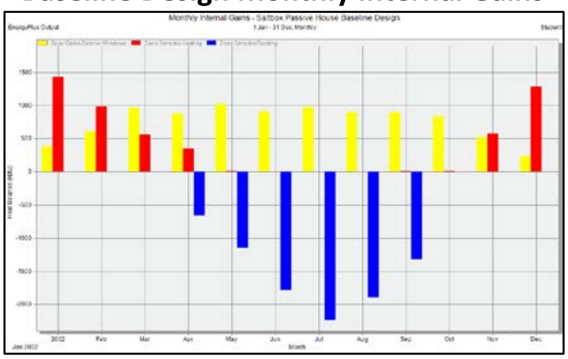


Figure 135: Passive House Saltbox Optimal Design Monthly Internal Gains

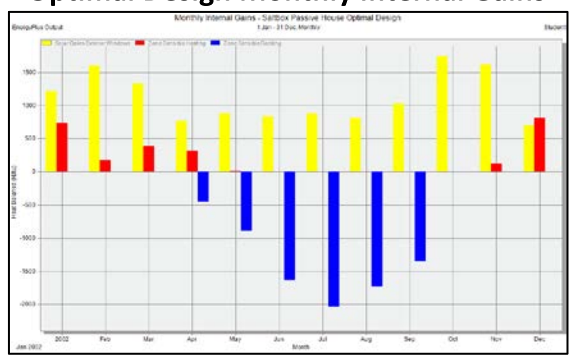


Figure 136: Passive House Saltbox Baseline Design Annual Internal Gains

Figure 137: Passive House Saltbox Optimal Design Annual Internal Gains

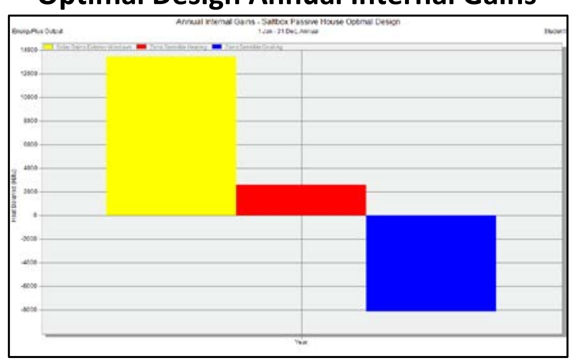


Table 14: Passive House Saltbox Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	5,233,000BTU	-2,654,000 BTU	Annual Heating Load	2,579,000 BTU
Annual Heating Cost	$194	-$99 (51%	Annual Heating Cost	$95
Annual Cooling Load	2,652 kWh	+278 kWh	Annual Cooling Load	2374 kWh
Annual Cooling Cost	$163	-$17(10%)	Annual Cooling Cost	$146
Total Conditioning Cost	**$357**	**-$116 (32.4%)**	**Total Conditioning Cost**	**$241**

By implementing passive solar design into the Passive House Saltbox, the annual heating load was reduced by 2.6 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $99 reduction of annual heating costs. As a result of the increased length of the shading devices, the annual cooling was decreased by 278kWh. At typical air conditioner efficiency and electricity costs this resulted in a $17 decrease of annual cooling costs. This resulted in a net reduction of $116 (32%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 138: Energy Star Saltbox Baseline Design Daily Temperatures Without Mechanical Systems

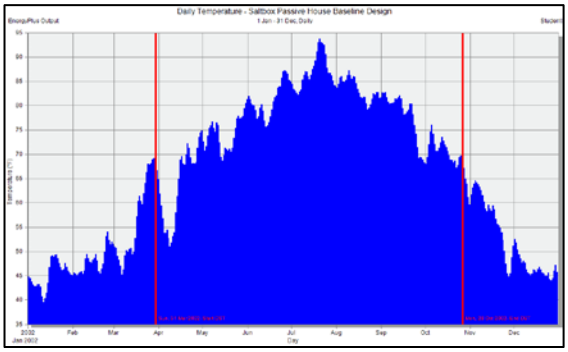


Figure 139: Energy Star Saltbox Optimal Design Daily Temperatures Without Mechanical Systems

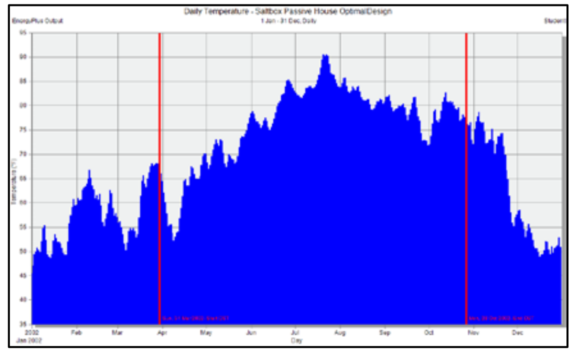


Figure 140: Energy Star Saltbox Baseline Design Monthly Temperatures Without Mechanical Systems

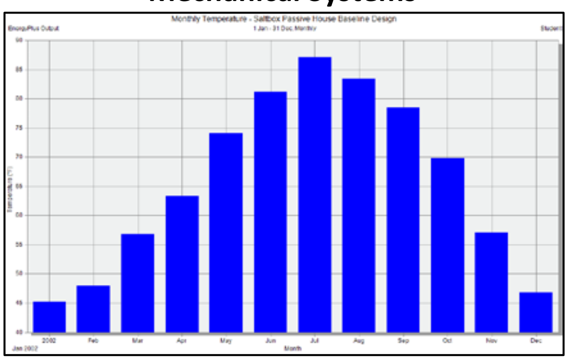
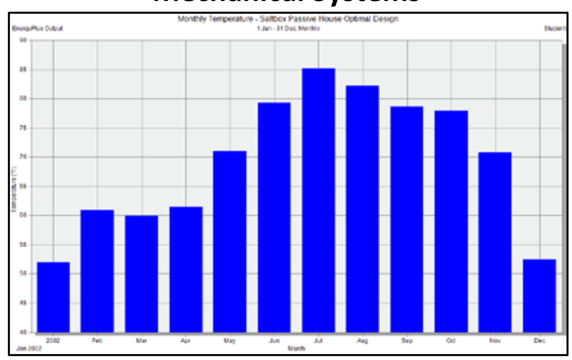


Figure 141: Energy Star Saltbox Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 7-12° warmer than the baseline design. Additionally, they minimize almost all of the daily temperature dips below 50°.

3.3 Cape

Figure 142: Cape House

3.3.1 IECC 2009 Cape

In order to observe the effect of orientation on the baseline design, the model was rotated 360° at 10° increments. For these rotations, 0° indicates the front façade is facing due South, 90° indicates facing due West, 180° indicates facing due North, and 270° indicates facing due East. As these figures show, the heating load is at its maximum when the front façade, which has the highest percentage of glazing, is facing North. The heating load is minimized when the front is facing due South. Conversly, the cooling load is minimized when the front is facing North, and maximised when it is facing East or West. Facing South also minimizes the cooling load. This is because the existing 1' overhang of the roof provides some shading to the windows when facing south.

Figure 143: IECC 2009 Cape Orientation Effect on Heating Load

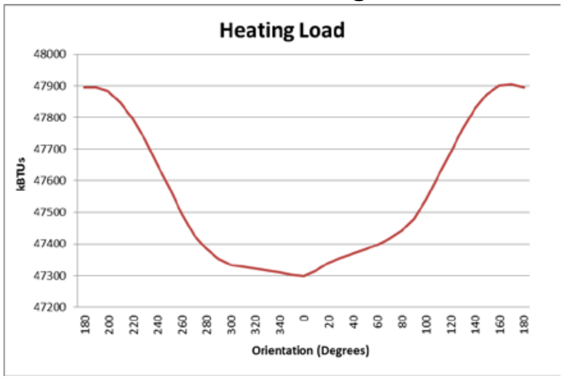
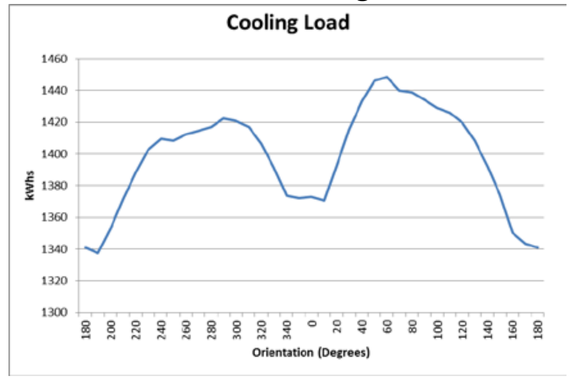


Figure 144: IECC 2009 Cape Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 145: IECC 2009 Cape Orientation Effect on Conditioning Cost

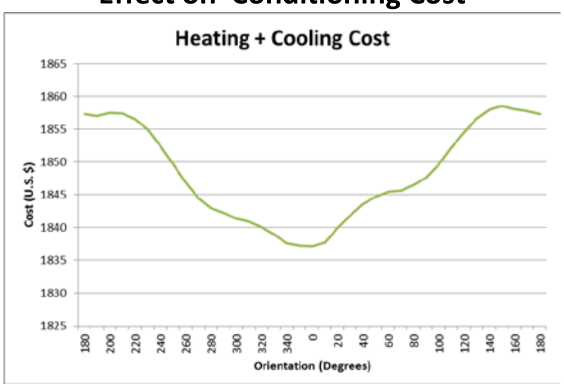
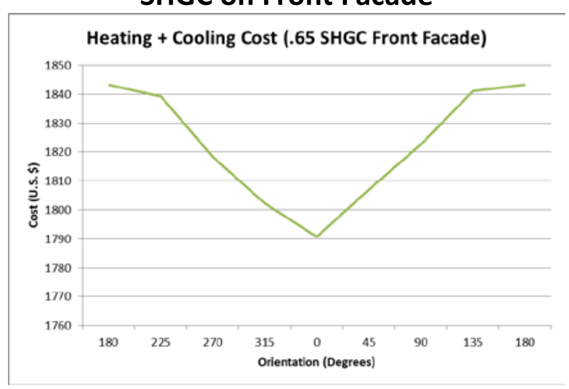


Figure 146: IECC 2009 Cape Orientation Effect on Conditioning Cost With .65 SHGC on Front Facade



Once it has been established that the optimal orientation is for the front façade to face due south, the appropriate solar heat gain coeffection of .65 can be applied to these windows. With these windows in place, the model is once again rotated, this time at 45° increments. Once again, it is evident that facing due South is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern façade, the cost has been reduced from $1847 to $1790, an annual savings of $57 (3%)

With the building at its optimal orientation of 0°, the effect of additional southern glazing, thermal mass, and the addition of shading in the form of window overhangs, can be added. The following figures illustrate the heating load, cooling load, and total cost, of every possible combination of these variables.

The combinations of these three variables are illustrated on sets of surface graphs. The graphs show the effect that the different combinations of thermal mass and overhang depth have on the heating and cooling loads as well as total annual cost. Each Set of these sets of graphs is based on an increasing amount of WWR, starting at the baseline value of 12.6 and increasing up to 31.5, at which point there is no room for additonal windows. (The set of graphs shown illustrate the WWR for the optimal design, in this case, WWR=31.5. The sets of graphs for the other WWRs can be found in appendix C)

Figure 147: IECC 2009 Cape Heating Loads with WWR=31.5

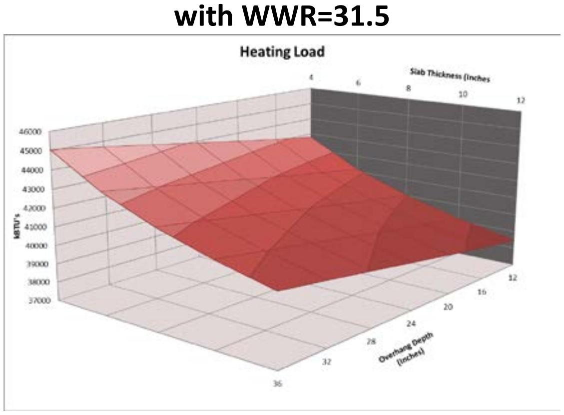


Figure 148: : IECC 2009 Cape Cooling Loads with WWR=31.5

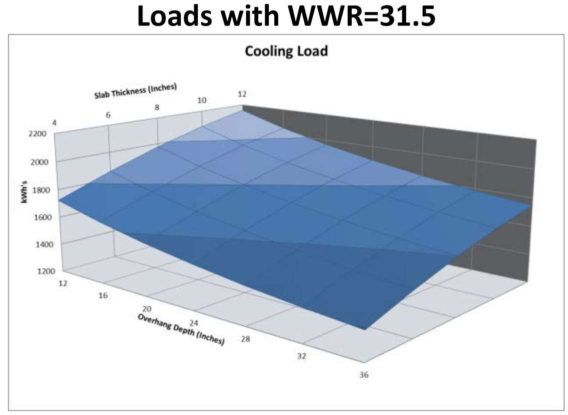
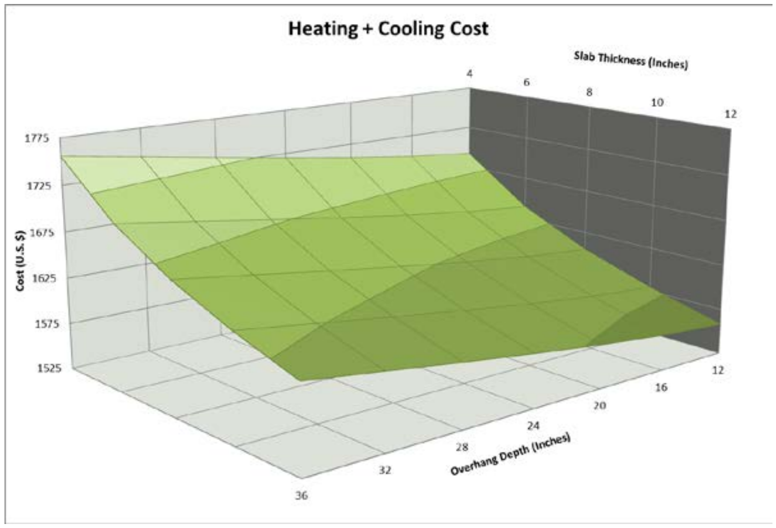


Figure 149: IECC 2009 Cape Conditioning Costs with WWR = 23.3



The Optimal design for the IECC 2009 Cape faces due south, has a WWR of 31.5 percent on the Southern facade, a 12” concrete slab, and the baseline 12” roof overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 150: IECC 2009 Cape Baseline Design Daily Internal Gains

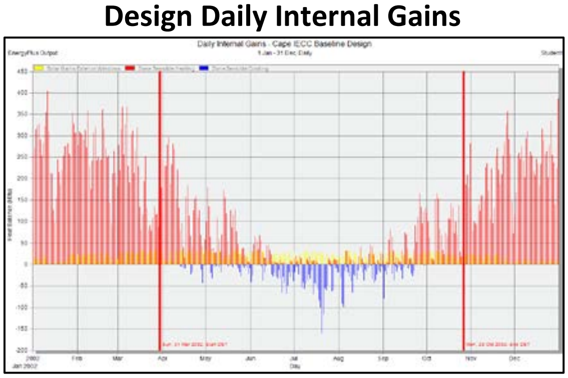


Figure 151: IECC 2009 Cape Optimal Design Daily Internal Gains

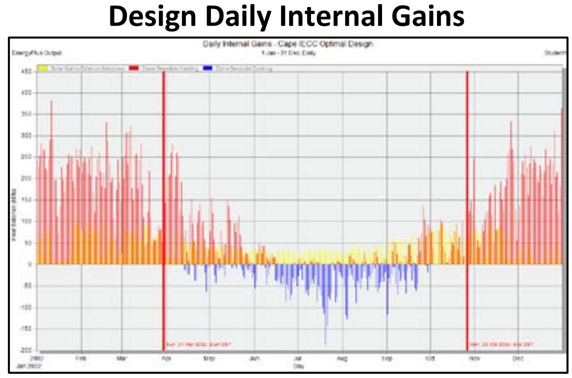


Figure 152: IECC 2009 Cape Baseline Design Monthly Internal Gains

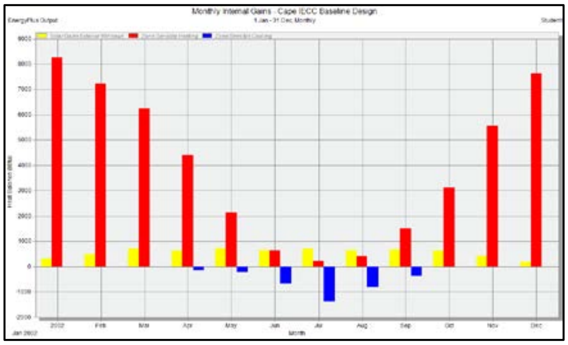


Figure 153: IECC 2009 Cape Optimal Design Monthly Internal Gains

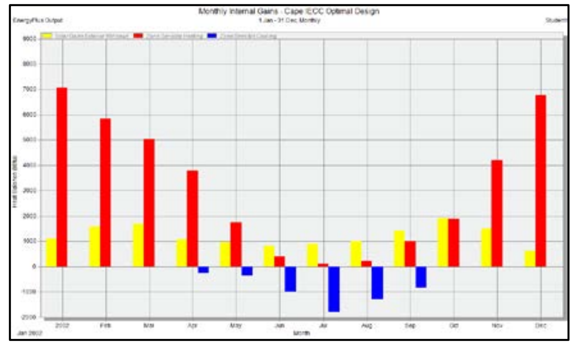


Figure 154: IECC 2009 Cape Baseline Design Annual Internal Gains

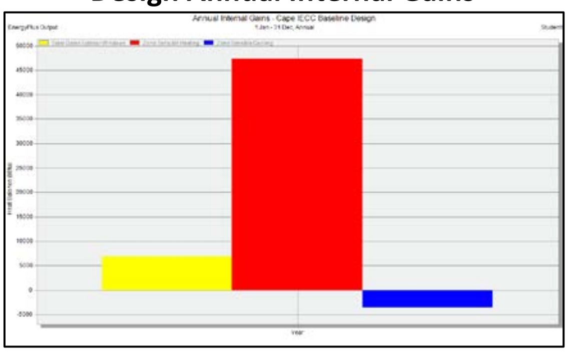


Figure 155: IECC 2009 Cape Optimal Design Annual Internal Gains

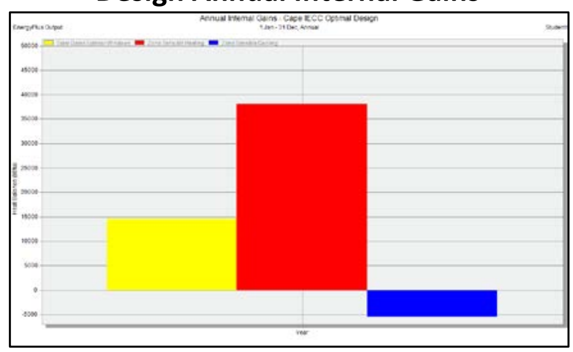


Table 15: Energy Star Saltbox Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	47,405,000BTU	-9,344,000 BTU	Annual Heating Load	38,061,000 BTU
Annual Heating Cost	$1,756	-$346 (19.7%	Annual Heating Cost	$1410
Annual Cooling Load	1,389 kWh	+688 kWh	Annual Cooling Load	2,077 kWh
Annual Cooling Cost	$85	+$43(50%)	Annual Cooling Cost	$128
Total Conditioning Cost	**$1,841**	**-$303 (16.5%)**	**Total Conditioning Cost**	**$1,538**

By implementing passive solar design into the 2009 IECC Cape, the annual heating load was reduced by 9.3 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $346 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 688 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $43 increase of annual cooling costs. This resulted in a net reduction of $303 (16.5%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 156: IECC 2009 Cape Baseline Design Daily Temperatures Without Mechanical Systems

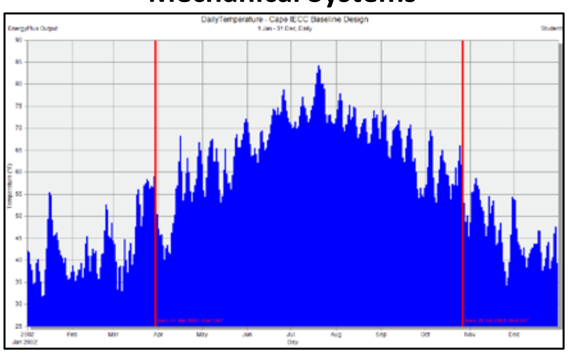


Figure 157: IECC 2009 Cape Optimal Design Daily Temperatures Without Mechanical Systems

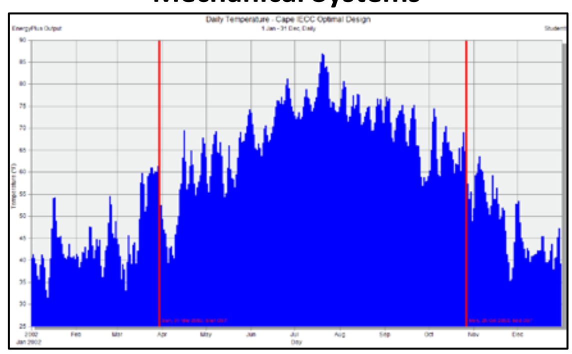


Figure 158: IECC 2009 Cape Baseline Design Monthly Temperatures Without Mechanical Systems

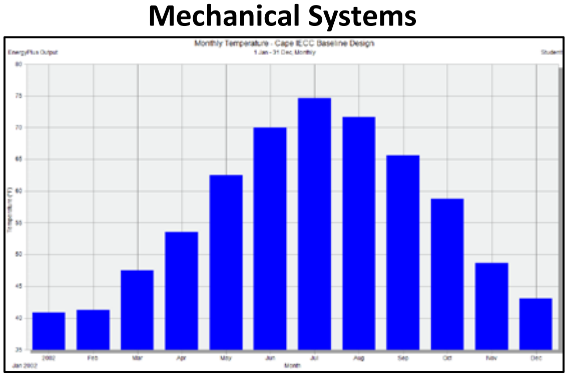
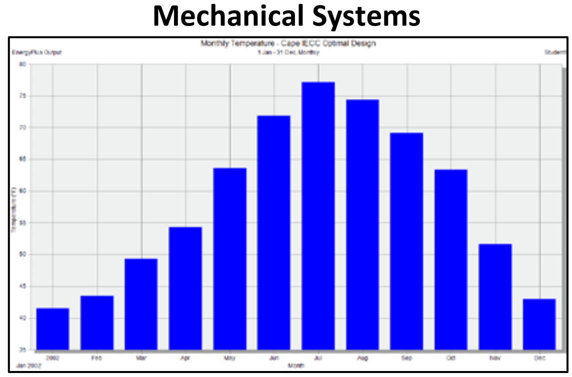


Figure 159: IECC 2009 Cape Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 2-4° warmer than the baseline design. Additionally, they minimize many of the daily temperature dips below 35°.

3.3.2 Energy Star Cape

The effects of orientation on the Energy Star model are quite similar to that of the IECC model. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling. Once again 0° is a close second for cooling as a result of the existing roof overhang.

Figure 160: Energy Star Cape Orientation Effect on Heating Load

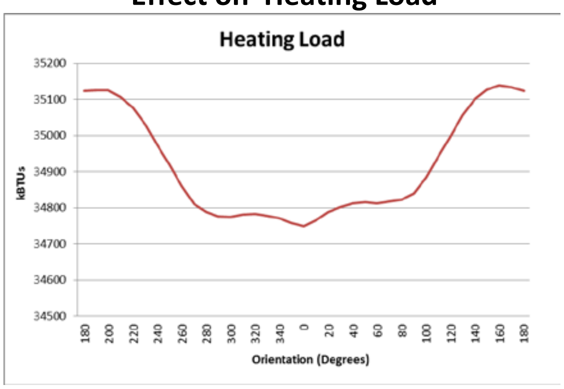
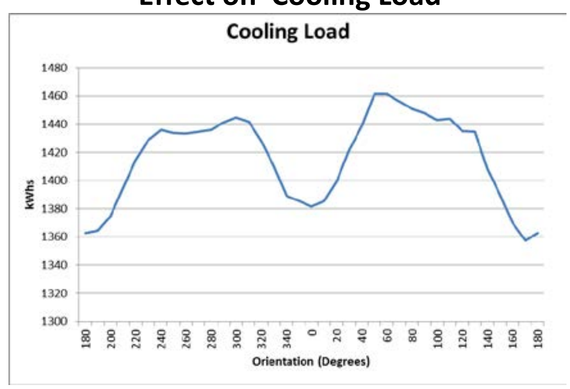


Figure 161: Energy Star Cape Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 162: Energy Star Cape Orientation Effect on Conditioning Cost

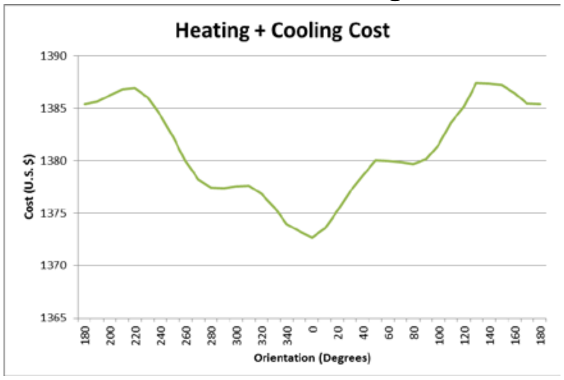
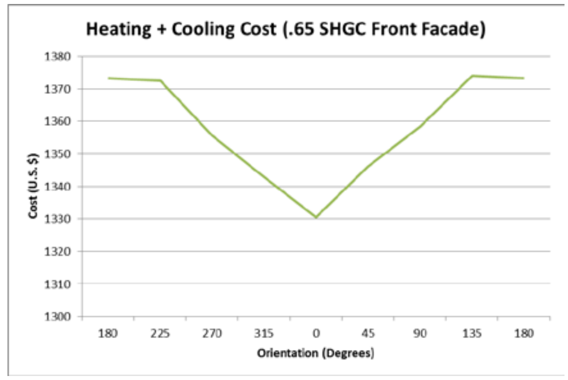


Figure 163: Energy Star Cape Orientation Effect on Conditioning Cost With .65 SHGC on Front Facade



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from $1,380 to $1,330, a savings of $50 (3.6%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design)

Figure 164: Energy Star Cape Saltbox Heating Loads with WWR=31.5

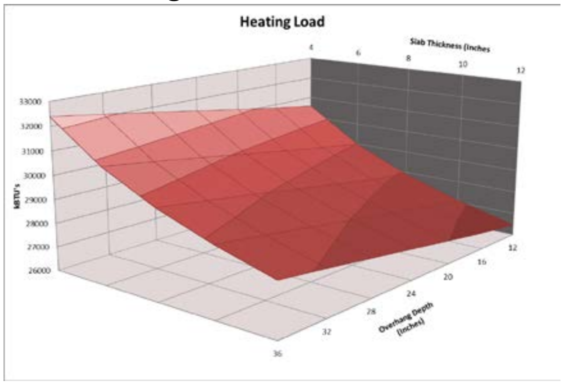


Figure 165: Energy Star Cape Saltbox Cooling Loads with WWR=31.5

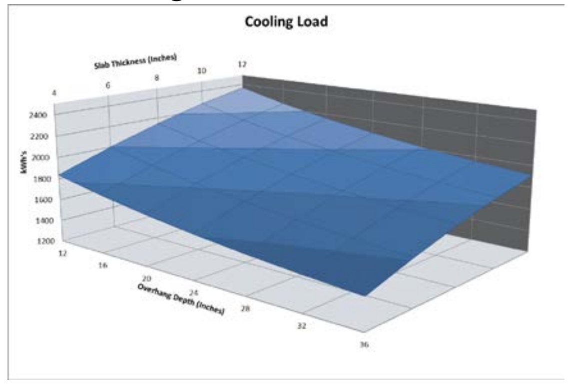
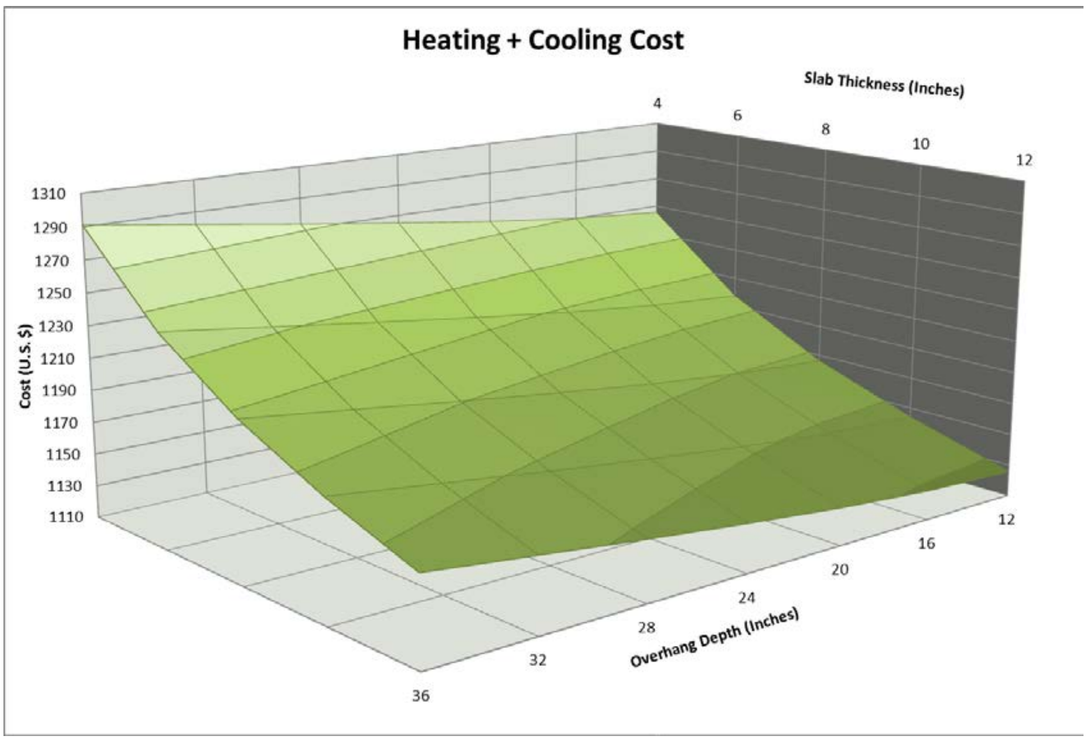


Figure 166: Energy Star Cape Saltbox Conditioning Costs WWR=31.5



The Optimal design for the Energy Star Cape faces due South, has a WWR of 31.5 percent on the Southern facade, a 12” concrete slab, and the baseline 12” roof overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 167: Energy Star Cape Baseline Design Daily Internal Gains

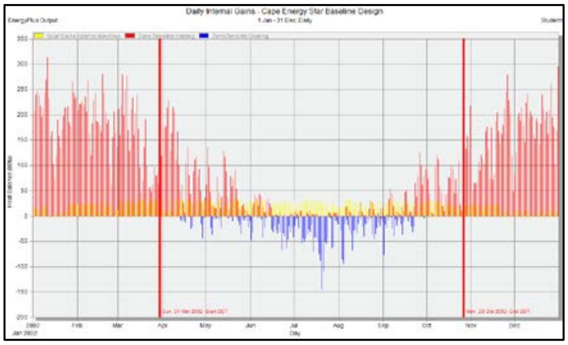


Figure 168: Energy Star Cape Optimal Design Daily Internal Gains

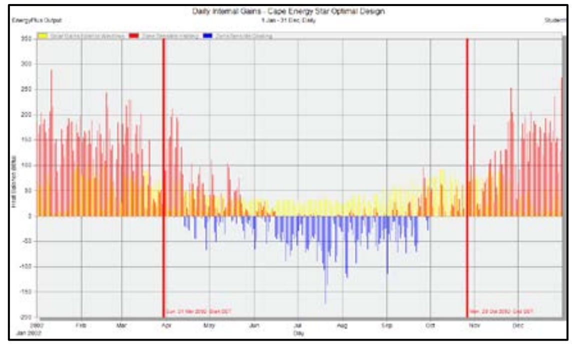


Figure 169: Energy Star Cape Baseline Design Monthly Internal Gains

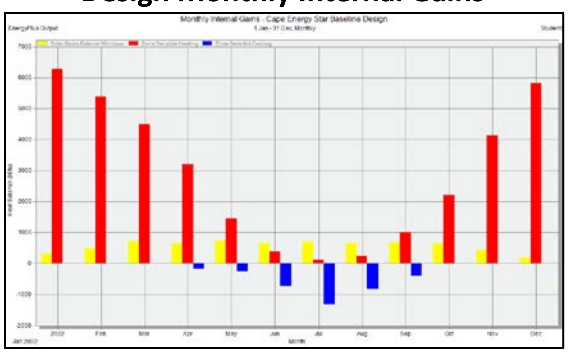


Figure 170: Energy Star Cape Optimal Design Monthly Internal Gains

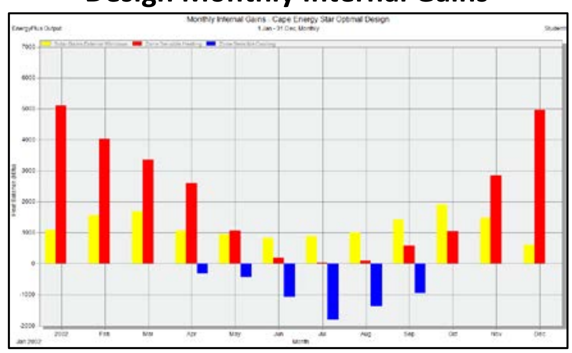


Figure 171: Energy Star Cape Baseline Design Annual Internal Gains

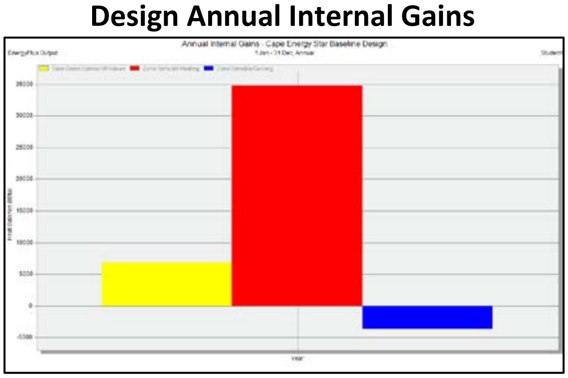


Figure 172: Energy Star Cape Optimal Design Annual Internal Gains

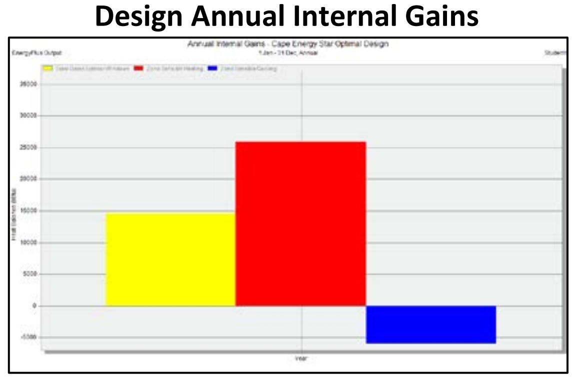


Table 16: Energy Star Cape Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	34,738,000BTU	-8,805,000 BTU	Annual Heating Load	25,933,000 BTU
Annual Heating Cost	$1,287	-$326 (25.3%	Annual Heating Cost	$961
Annual Cooling Load	1,387 kWh	+782 kWh	Annual Cooling Load	2,169 kWh
Annual Cooling Cost	$85	+$48(56.4%)	Annual Cooling Cost	$133
Total Conditioning Cost	**$1,372**	**-$278 (20.2%)**	**Total Conditioning Cost**	**$1,094**

By implementing passive solar design into the Energy Star Cape, the annual heating load was reduced by 8.8 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $326 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 782 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $48 increase of annual cooling costs. This resulted in a net reduction of $278 (20.2%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 173: Energy Star Cape Baseline Design Daily Temperatures Without Mechanical Systems

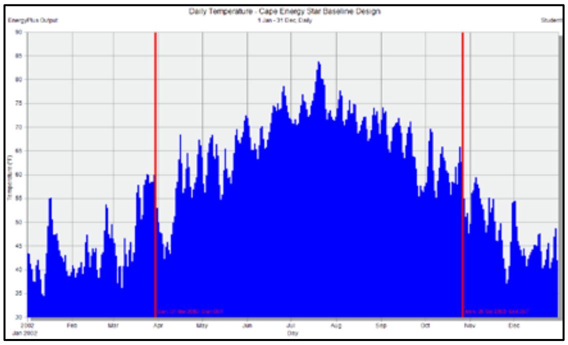


Figure 174: Energy Star Cape Optimal Design Daily Temperatures Without Mechanical Systems

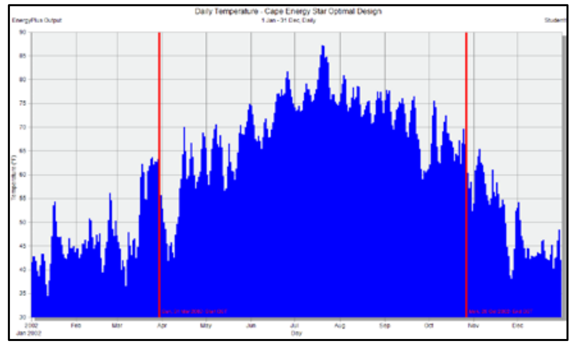


Figure 175: Energy Star Cape Baseline Design Monthly Temperatures Without Mechanical Systems

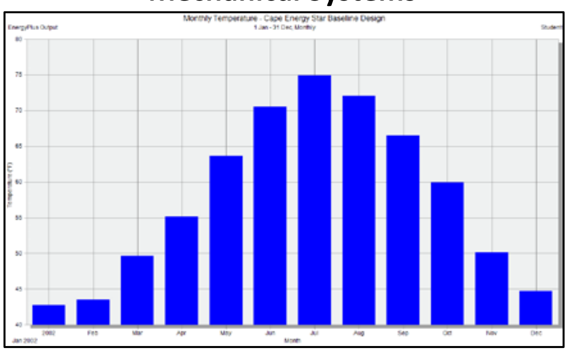
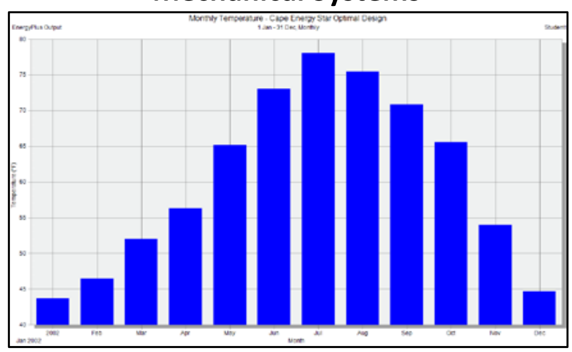


Figure 176: Energy Star Saltbox Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 2-5° warmer than the baseline design. Additionally, they minimize many of the daily temperature dips below 40°.

3.3.3 Energy Star-Passive House Cape

The effects of orientation on the Energy Star – Passive House Average model are quite similar to that of the previous models. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling. Once again 0° is a close second for cooling as a result of the roof overhang over the second floor windows.

Figure 177: Energy Star-Passive House Cape Orientation Effect on Heating Load

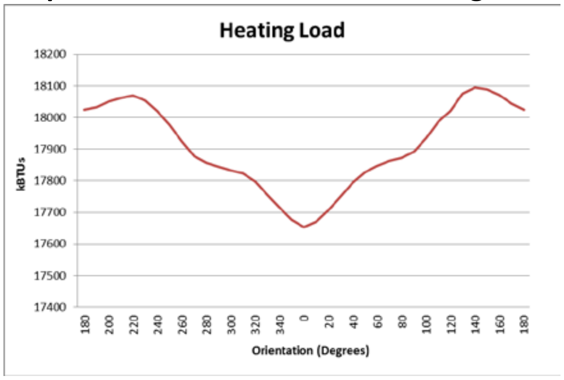
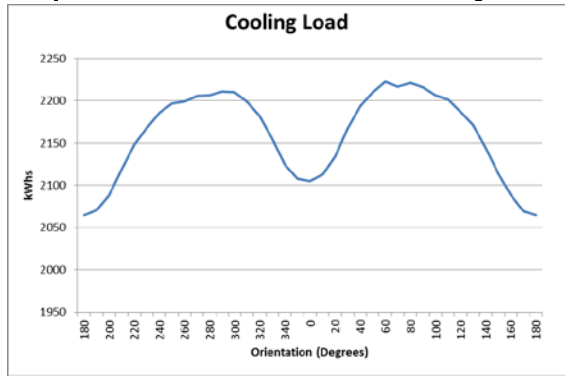


Figure 178: Energy Star-Passive House Cape Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 179: Energy Star-Passive House Cape Orientation Effect on Conditioning Cost

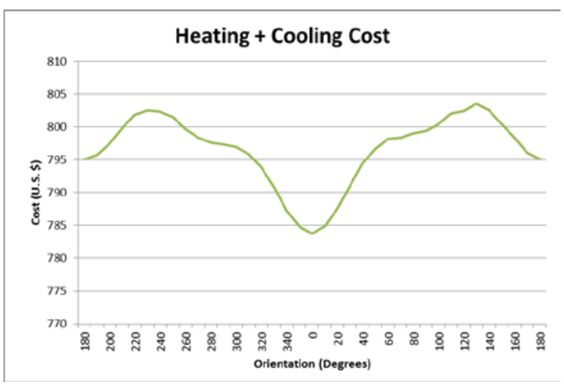
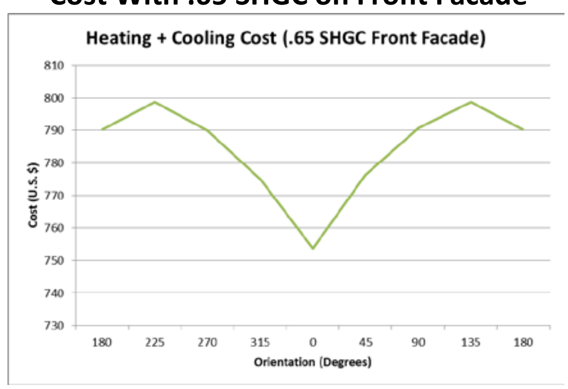


Figure 180: Energy Star-Passive House Cape Orientation Effect on Conditioning Cost With .65 SHGC on Front Facade



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from $799 to $753, a savings of $46 (5.7%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design)

Figure 181: Energy Star- Passive House Cape Heating Loads with WWR=31.5

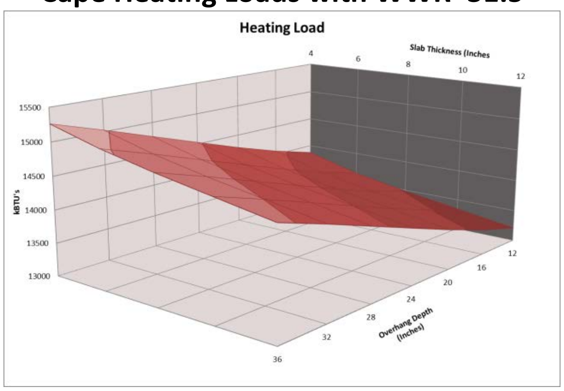


Figure 182: Energy Star- Passive House Cape Cooling Loads with WWR=31.5

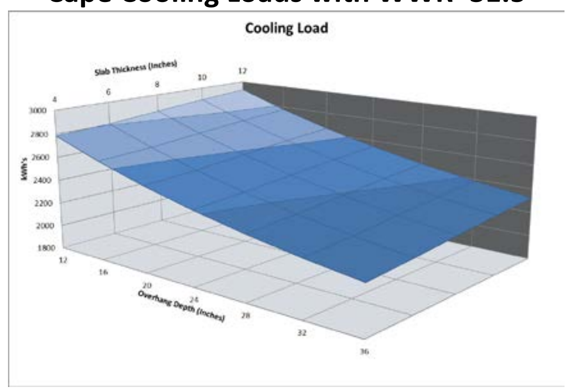
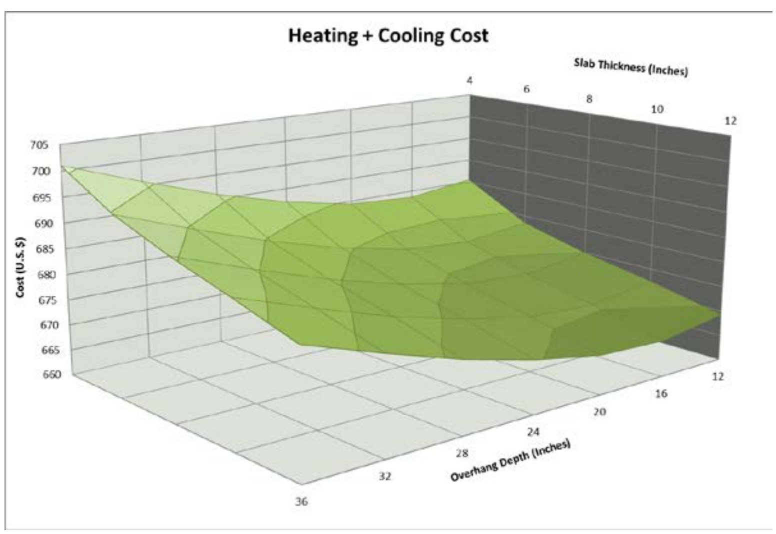


Figure 183: Energy Star- Passive House Cape Conditioning Costs with WWR=31.5



The Optimal design for the Energy Star – Passive House Cape faces due south, has a WWR of 31.5 percent on the Southern facade, a 12” concrete slab, and the baseline 16” roof overhang. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 184: Energy Star-Passive House Cape Baseline Design Daily Internal Gains

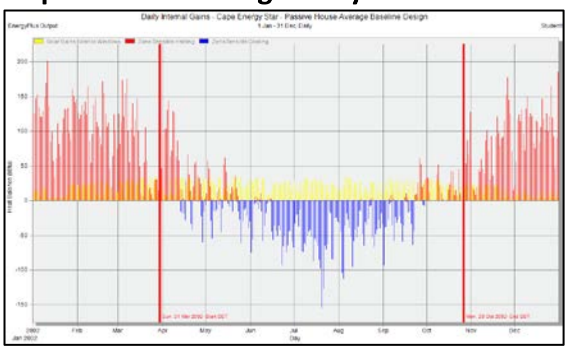


Figure 185: Energy Star-Passive House Cape Optimal Design Daily Internal Gains

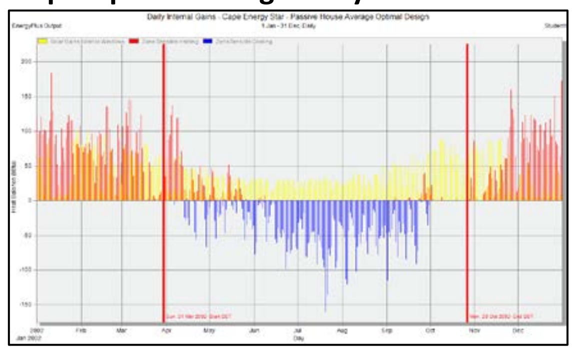


Figure 186: Energy Star-Passive House Cape Baseline Design Monthly Internal Gains

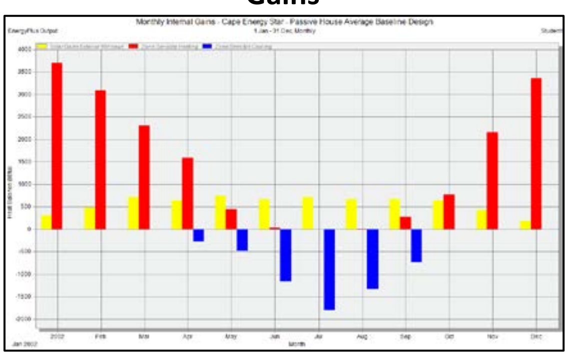


Figure 187: Energy Star-Passive House Cape Optimal Design Monthly Internal Gains

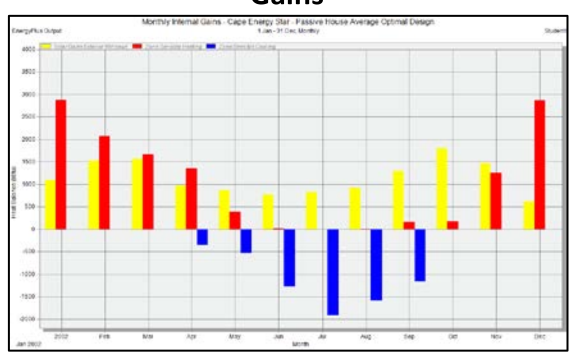


Figure 188: Energy Star-Passive House Cape Baseline Design Annual Internal Gains

Figure 189: Energy Star-Passive House Cape Optimal Design Annual Internal Gains

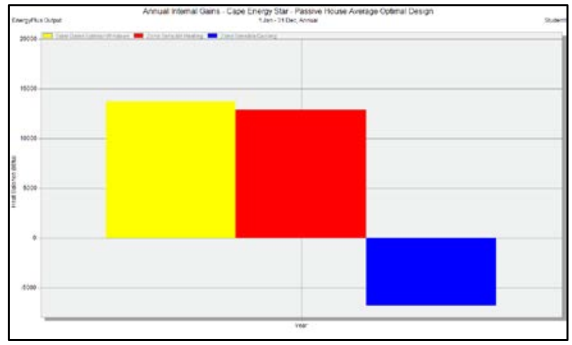


Table 17: Energy Star-Passive House Cape Baseline-Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	17,725,000BTU	-4,886,000 BTU	Annual Heating Load	12,839,000 BTU
Annual Heating Cost	$657	-$182 (27.7%	Annual Heating Cost	$475
Annual Cooling Load	2,101 kWh	+350 kWh	Annual Cooling Load	2,451 kWh
Annual Cooling Cost	$129	+$22(17%)	Annual Cooling Cost	$151
Total Conditioning Cost	**$786**	**-$160 (20.3%)**	**Total Conditioning Cost**	**$626**

By implementing passive solar design into the Energy Star Cape, the annual heating load was reduced by 4.8 million BTU’s. With typical furnace efficiency and fuel costs this resulted in a $182 reduction of annual heating costs. As a result of the increased solar gains in the summer months, the annual cooling was increased by 350 kWh. At typical air conditioner efficiency and electricity costs this resulted in a $22 increase of annual cooling costs. This resulted in a net reduction of $160 (20.3%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 190: Energy Star-Passive House Cape Baseline Design Daily Temperatures Without Mechanical Systems

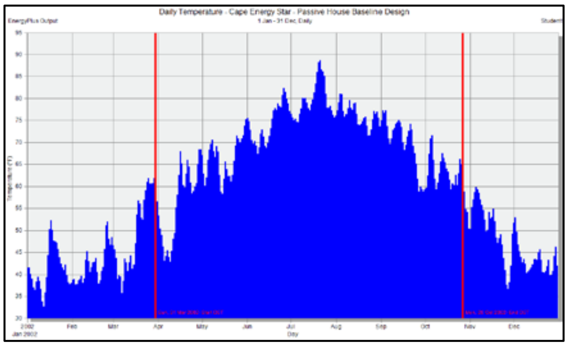


Figure 191: Energy Star-Passive House Cape Optimal Design Daily Temperatures Without Mechanical Systems

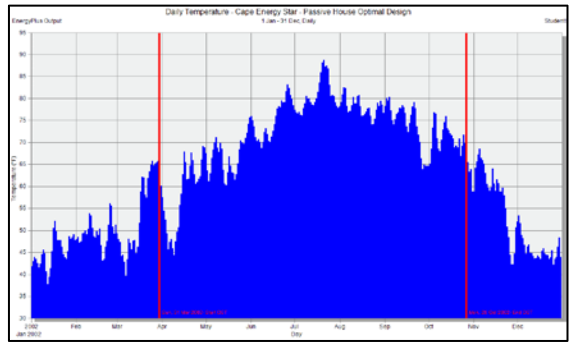


Figure 192: Energy Star-Passive House Cape Baseline Design Monthly Temperatures Without Mechanical Systems

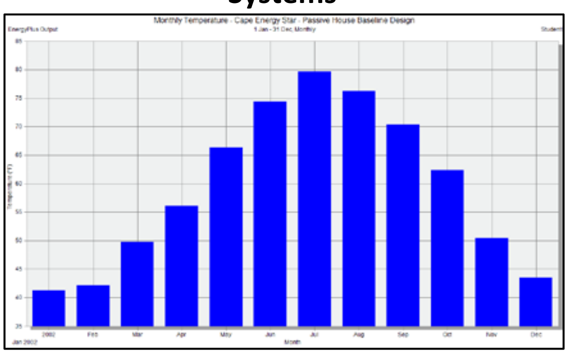
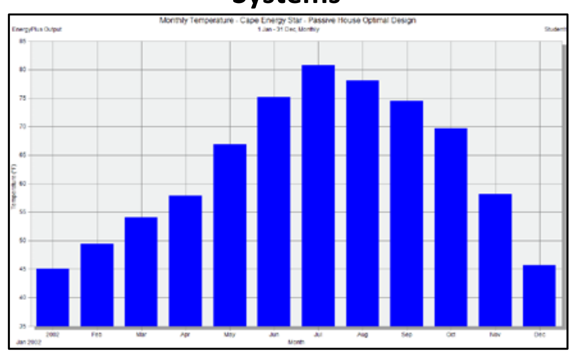


Figure 193: Energy Star-Passive House Cape Optimal Design Monthly Temperatures Without Mechanical Systems



These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 4-7° warmer than the baseline design. Additionally, they minimize many of the daily temperature dips below 45°.

3.3.4 Passive House Cape

The effects of orientation on the Passive House model are quite similar to that of the previous models. O° is the optimal orientation for heating purposes, and 180° is the the optimal for cooling.

Figure 194: Passive House Cape Orientation Effect on Heating Load

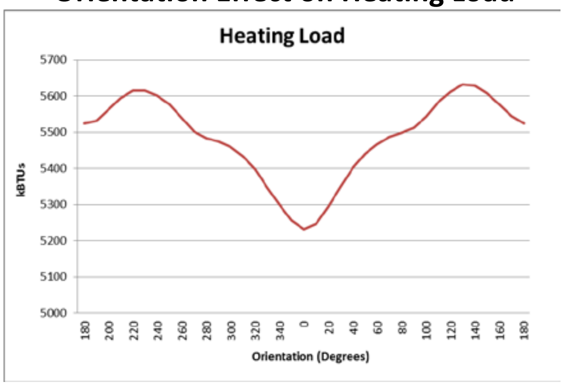
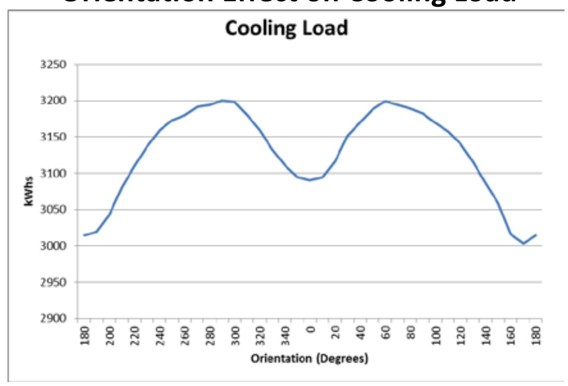


Figure 195: Passive House Cape Orientation Effect on Cooling Load



When the fuel costs for the heating and cooling loads are incorporated, facing due south proves to be the most cost effective orientation.

Figure 196: Passive House Cape Orientation Effect on Conditioning Costs

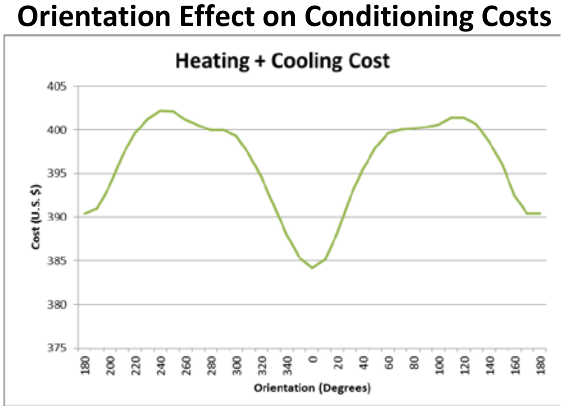
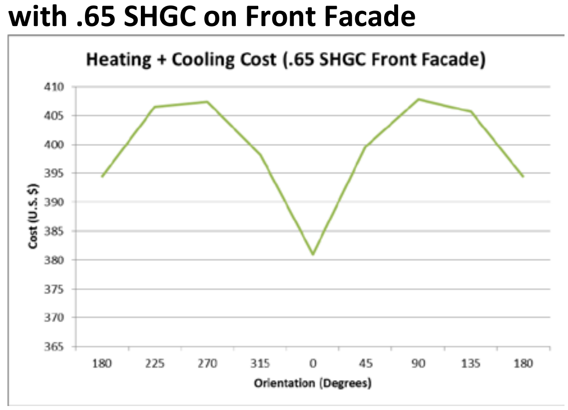


Figure 197: Passive House Cape Orientation Effect on Conditioning Costs with .65 SHGC on Front Facade



With a .65 SHGC applied to the prospective Southern façade the building is once more rotated, and again, facing due south is the optimal orientation. By rotating the building from facing West, to facing South, and using a SHGC of .65 on the Southern facade, the cost has been reduced from $400 to $380, a savings of $20 (5%).

The following surface graphs show the relationship between WWR, thermal mass, and overhang depth. (The set of graphs shown illustrate the WWR for the optimal design.)

Figure 198: Passive House Cape Heating Loads with WWR=25.2

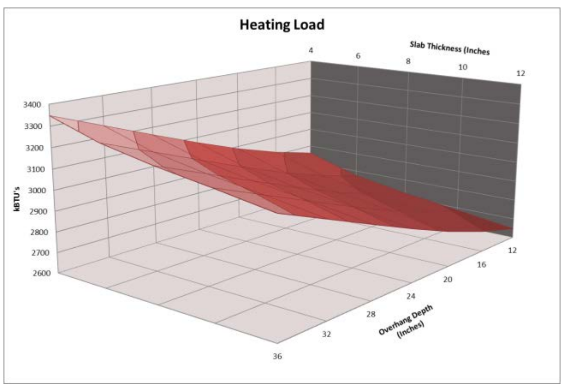


Figure 199: Passive House Cape Cooling Loads with WWR=25.2

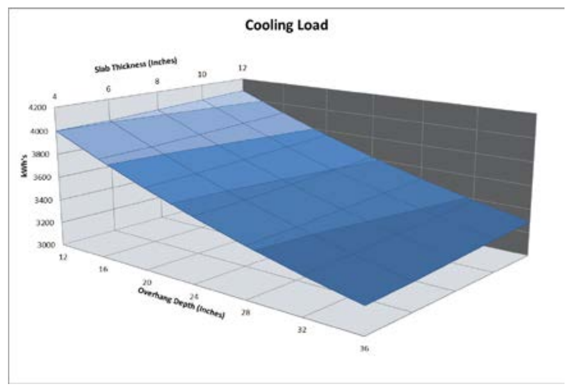
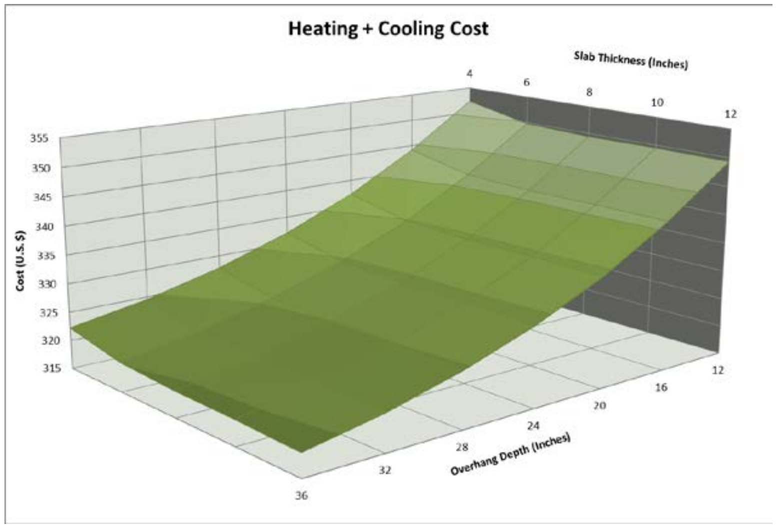


Figure 200: Passive House Cape Conditioning Costs with WWR=25.2



The Optimal design for the Passive House Cape faces due south, has a WWR of 25.2 percent, a 12” concrete slab, and a 36” window overhang. The super insulated and air tight construction of the passive house model results in the heating loads being smaller than the cooling loads which are primarily a result of solar gains and various internal gains. As a result, cooling is the driving factor of the design, which is why this model doesn’t reach the maximum possible WWR, and does reach the maximum shading length. With the optimized design realized, the winter cooling loads are removed from the baseline and optimal designs, and the models are re-simulated. The Following figures show the comparison of solar gains and subsequent heating and cooling loads between the baseline and optimal designs.

Figure 201: Passive House Cape Baseline Design Daily Internal Gains

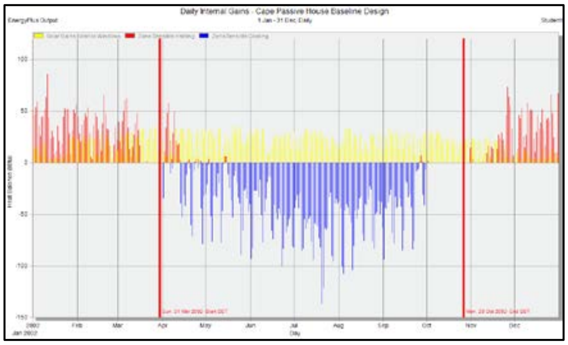


Figure 202: Passive House Cape Optimal Design Daily Internal Gains

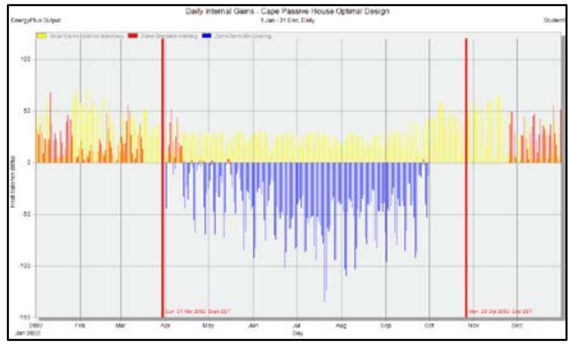


Figure 203: Passive House Cape Baseline Design Monthly Internal Gains

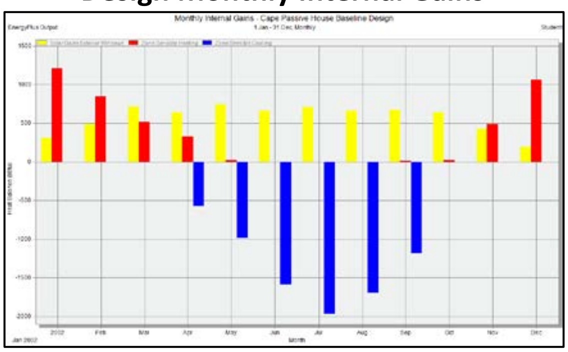


Figure 204: Passive House Cape Optimal Design Monthly Internal Gains

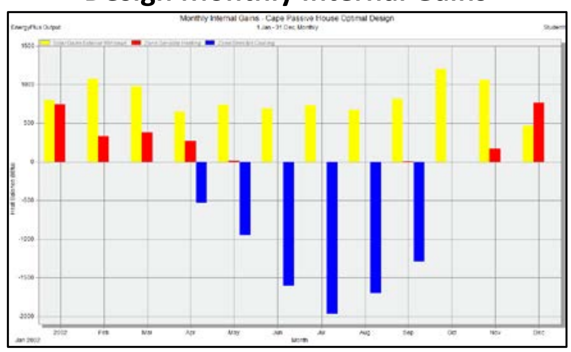


Figure 205: Passive House Cape Baseline Design Annual Internal Gains

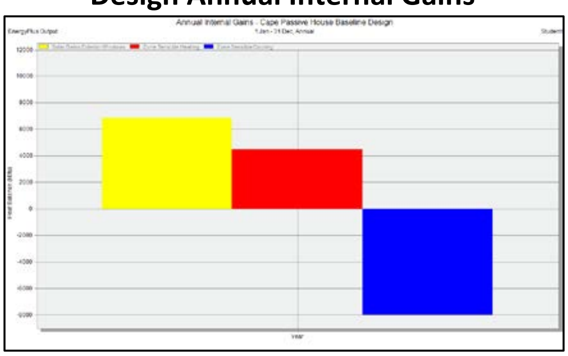


Figure 206: Passive House Cape Optimal Design Annual Internal Gains

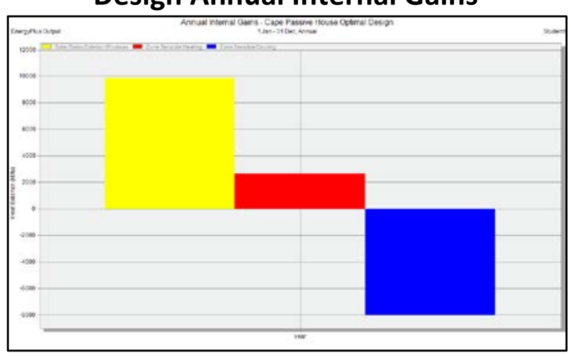


Table 18: Passive House Cape Baseline - Optimal Design Comparison

Baseline Design		Difference	Optimal Design	
Annual Heating Load	5,213,000BTU	-2,109,000 BTU	Annual Heating Load	3,104,000 BTU
Annual Heating Cost	$193	-$78 (40%	Annual Heating Cost	$115
Annual Cooling Load	2,828 kWh	+57kWh	Annual Cooling Load	2,885 kWh
Annual Cooling Cost	$174	+$3 (1.7%)	Annual Cooling Cost	$177
Total Conditioning Cost	**$367**	**-$75 (20.4%)**	**Total Conditioning Cost**	**$292**

By implementing passive solar design into the Passive House Saltbox, the annual heating load was reduced by 2.1 million BTU's. With typical furnace efficiency and fuel costs this resulted in a $78 reduction of annual heating costs. As a result of the increased solar gains, the annual cooling was increased by 57kWh. At typical air conditioner efficiency and electricity costs this resulted in a $3 increase of annual cooling costs. This resulted in a net reduction of $75 (20.4%) of conditioning costs as a result of implementing passive solar design.

The following figures show how the baseline and optimal designs perform without the use of mechanical heating and cooling systems.

Figure 207: Passive House Cape Baseline Design Daily Temperatures Without Mechanical Systems

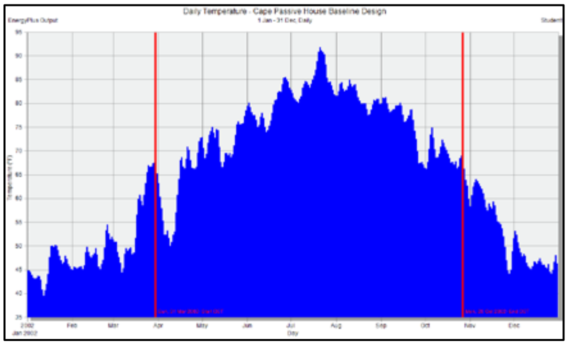


Figure 208: Passive House Cape Optimal Design Daily Temperatures Without Mechanical Systems

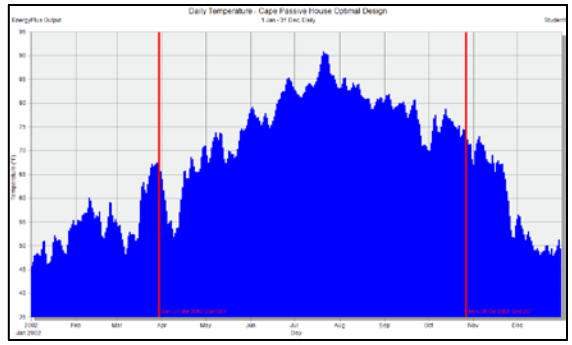


Figure 209: Passive House Cape Baseline Design Monthly Temperatures Without Mechanical Systems

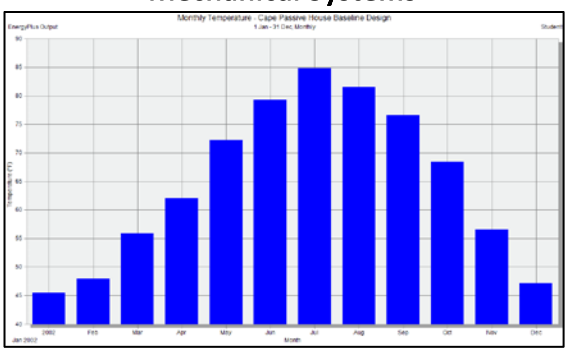
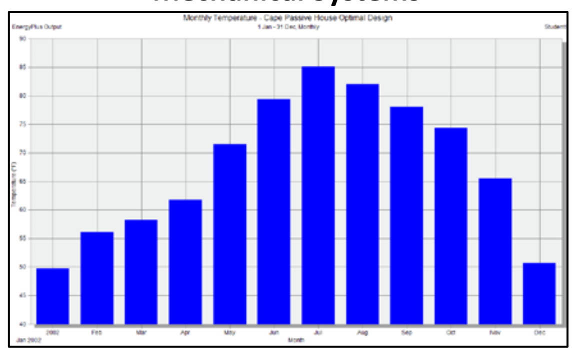


Figure 210: Passive House Cape Optimal Design Monthly Temperatures Without Mechanical Systems



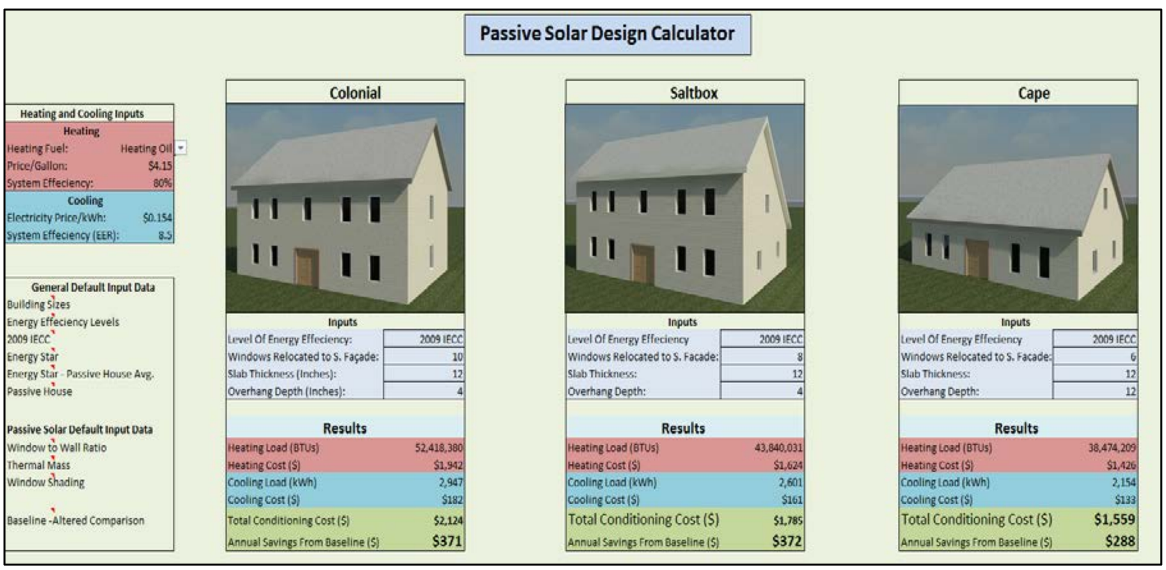
These figures show that without mechanical heating and cooling, the monthly average of the optimal design stays between 5-10° warmer than the baseline design. Perhaps more importantly, they minimize many of the daily temperature dips below 50°.

CHAPTER 4

EXCEL CALCULATOR

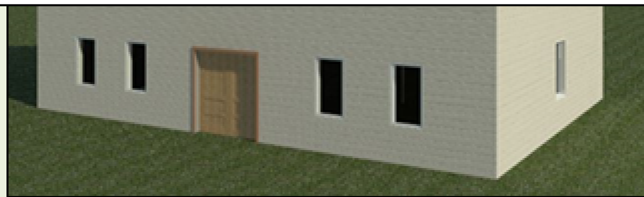
After running every combination of variables in DesignBuilder I had a dataset of 3,200 simulations that stretched across the 3 architectural styles, and 4 levels of energy efficiency. Considering the number of input variables and the size of the data set, it was difficult to show all of these building in any sort of traditional graph. In order to clearly and easily covey the results of each of these simulations, I created an Excel calculator that allows the user to select all of the desired inputs, and view the subsequent outputs.

Figure 211: Excel Calculator Interface



The calculator allows the user to select any combination of the simulated window to wall ratio of the front façade, slab thickness, and overhang depth.

Figure 212: Excel Calculator Passive Solar Inputs



Inputs	
Level Of Energy Effeciency:	2009 IECC
Windows Relocated to S. Façade:	10
Slab Thickness (Inches):	12
Overhang Depth (Inches):	4

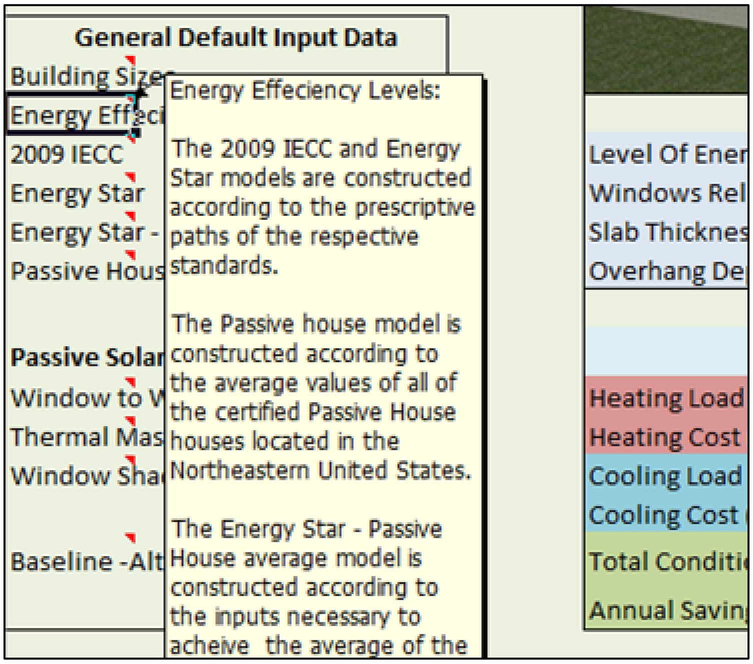
In addition to the passive solar variables, the user can also select properties of the conditioning systems. They can choose the heating fuel from a list of Heating Oil, Natural Gas, Propane, and Wood Pellets, additionally they choose the price of the fuel and the system efficiency. They also choose the Price of electricity for cooling as well as the system efficiency.

Figure 213: Excel Calculator Conditioning System Inputs

Heating and Cooling Inputs	
Heating	
Heating Fuel:	Heating Oil
Price/Gallon:	$4.15
System Effeciency:	80%
Cooling	
Electricity Price/kWh:	$0.154
System Effeciency (EER):	8.5

In addition to all of the inputs, the calculator provides concise explanations of the general input data for the different levels of energy efficiency, the passive solar input data, and the comparison between the baseline and altered designs, as is described in detail in the methods section.

Figure 214: Excel Calculator Explanation Section



In addition to being an easy way to view all of the my results, this calculator provides an easy way to compare effects of different configurations of passive solar variables, as well as illustrating how the importance of each passive variables changes as the level of energy efficiency changes.

CHAPTER 5

SUMMARY AND DISCUSSION

After all the variations of each building were simulated, and the conditioning costs were calculated, it was important to see the side by side comparisons of the baseline and optimal models, in order to decide if the potential energy savings warrant the extra design considerations. As tables 19-21 illustrate, with each level of added energy efficiency, there is an increase in percent savings, but a decrease in total savings from implementing the passive solar features. This is a result of an increasingly smaller demand for heating, resulting in a diminished potential for reducing the heating load through passive solar design. Additionally, as the buildings get more energy efficient, and the infiltration rates are reduced, which makes the buildings become more susceptible to overheating, which is compounded by increasing the level of southern glazing.

In addition to the side by side cost analysis, images 217-219 show the difference in solar gains in BTU/ft^2 during the heating season. In addition, the optimal summer model is shown with solar ray tracing which illustrates the effectiveness of the shading devices. These specific images shown are at noon on June 21. It is important to remember that the cooling season begins before and extends long after June 21, so while the overhangs displayed appear to completely block unwanted gains, earlier and later in the season they become less effective, thus the need for longer shading devices in the more cooling oriented models. The passive solar features for these models are at the optimal level, which resulted in the lowest operating cost for the Energy Star-Passive House Model

5.1 Summary of Colonial

Figure 215: Colonial Baseline Design Image

Figure 216: Colonial Optimal Design Image

Figure 217: Colonial Baseline Design Winter Insolation

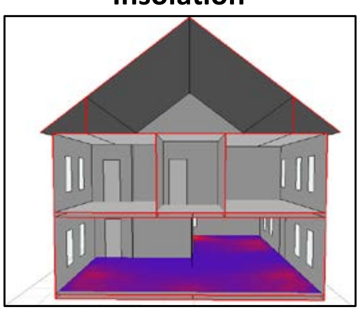


Figure 218: Colonial Optimal Design Winter Insolation

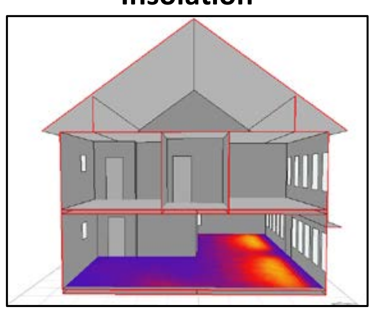
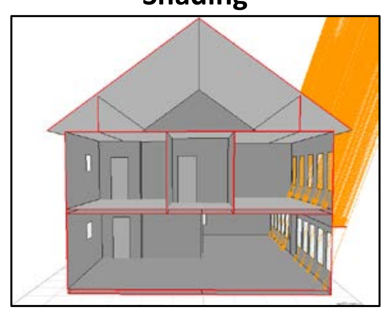


Figure 219: Colonial Optimal Design Summer Shading



(Optimal Design Images from Energy Star-Passive House Optimal Design, in which, southern WWR = 26, Overhang = 20, Slab = 12”)

Table 19: Colonial Baseline - Optimal Design Comparison Summary

Level of Energy Efficiency	Baseline Design (Annual Cost)	Savings (Annual Savings)	Optimal Design (Annual Cost)
2009 IECC Model	$2,490	$422 (17%)	$2,068
Energy Star Model	$1,836	$372 (20.2%)	$1,464
Energy Star-Passive House Avg. Model	$1,088	$253 (23.2%)	$835
Passive House Model	$509	$150 (29%)	$359

5.2 Summary of Saltbox

Figure 220: Saltbox Baseline Design Image

Figure 221: Saltbox Optimal Design Image

Figure 222: Saltbox Baseline Design Winter Insolation

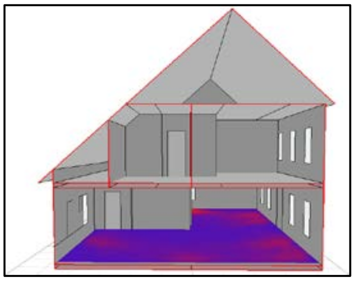


Figure 223: Saltbox Optimal Design Winter Insolation

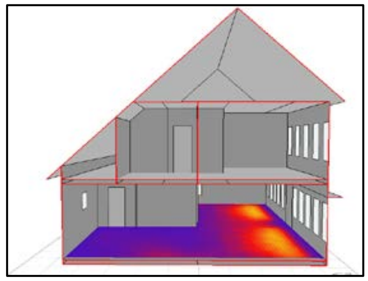
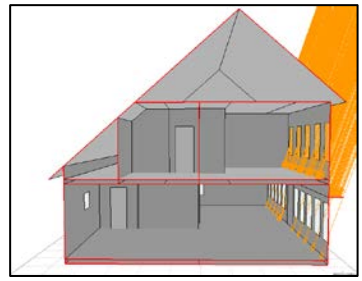


Figure 224: Saltbox Optimal Design Summer Shading



(Optimal Design Images from Energy Star-Passive House Optimal Design, in which, southern WWR = 23.3, Overhang = 20, Slab = 12")

Table 20: Saltbox Baseline - Optimal Design Comparison Summary

Level of Energy Efficiency	**Baseline Design (Annual Cost)**	**Savings (Annual Savings)**	**Optimal Design (Annual Cost)**
2009 IECC Model	$2,152	$398 (18.5%)	$1,754
Energy Star Model	$1,589	$363 (22.8%)	$1,226
Energy Star–Passive House Avg. Model	$923	$227 (24.6%)	$696
Passive House Model	$357	$116 (32.4%)	$241

5.3 Summary of Cape

Figure 225: Cape Baseline Design Image

Figure 226: Cape Optimal Design Image

Figure 227: Cape Baseline Design Winter Insolation

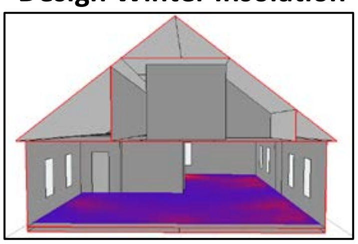


Figure 228: Cape Optimal Design Winter Insolation

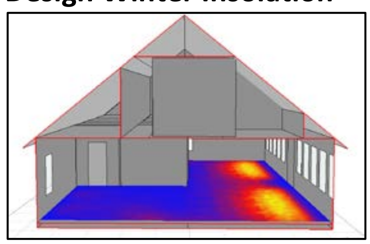
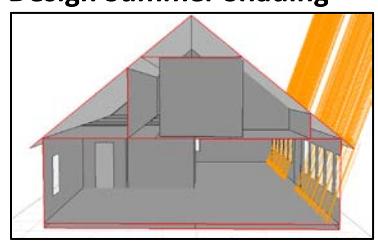


Figure 229: Cape Optimal Design Summer Shading



(Optimal Design Images from Energy Star-Passive House Optimal Design, in which, southern WWR = 31.5, Overhang = 16, Slab = 12")

Table 21: Cape Baseline - Optimal Design Comparison Summary

Cape	Baseline Design (Annual Cost)	Savings (Annual Savings)	Optimal Design (Annual Cost)
2009 IECC Model	$1,841	$303 (16.5%)	$1,538
Energy Star Model	$1,372	$278 (20.2%)	$1,094
Energy Star–Passive House Avg. Model	$786	$160 (20.3%)	$626
Passive House Model	$367	$75 (20.4%)	$292

5.4 Discussion

Within the building industry, clients, builders, architects, and policy makers are clamoring to increase the energy efficiency of buildings. This is often accomplished through the use of complicated, expensive products. While these measures play an important role, they often overshadow the simplicity and nearly free benefits that can be achieved through passive solar design. As this research shows, passive solar design can be implemented into traditional New England architectural styles, and provide significant savings on annual heating and cooling loads.

The beauty of passive solar design comes from its operational simplicity. While it does take some design and construction considerations, once it is built, it functions for the life of the building without the need for the maintenance, repair, and fuel that more complicated systems require. Additionally, the features of a passive solar structure are already present in every building, just not in the right places or in the necessary quantity. This means that the construction requires no new or specialized training and most of the material would already be present in the design. As this research shows, the following variables each play and important and integrated role in a successful passive solar structure.

Orientation: All of the Models performed best when the front facade was facing directly south, however, the effectiveness of the optimal designs were only reduced by a few percent when the building faced within 20 degrees of due south. After 20 degrees, the heating load dramatically increased as the winter solar gains were reduced. The cooling load also drastically increased as the shading devices became less effective at blocking the East and Western summer sunlight. This was most problematic with the Passive House model, as its conditioning costs were cooling load dominated.

Window to wall ratio: Each window that was relocated to the southern facade reduced the heating load but increased the cooling load. In the IECC models, the heating loads so far exceeded the cooling loads that the increased cooling loads were not significant enough to outweigh the benefits of the heating. As the level of energy efficiency increased the heating loads were reduced, however, one variable of energy efficiency was the infiltration rate. As the infiltration rate was reduced, the natural ventilation that helped prevent overheating and subsequent need for cooling was reduced. As a result, the more efficient models were more prone to overheating, which incrementally decreased the gains from adding to the southern WWR, relative to the less efficient models. The benefits of relocating windows to the southern façade were substantial for the IECC, Energy Star, and Energy Star-Passive House Average models, however, the Passive house models had minimal reductions or increased conditioning costs from relocating windows.

Control: Each incremental increase in the overhang length reduced the cooling load but also increased the heating load. For the IECC models, the cooling loads were low enough that the optimal designs have minimal or no overhangs. As the level of energy efficiency increases and the heating loads decrease, and cooling loads increase, the overhangs become larger, and produce greater savings. In the Passive House models, the cooling dominated costs resulted in 36 inch overhangs for all styles, which reduced total conditioning costs by over $100, as well as reducing overheating during the months in which the air conditioning was not active.

Considering that the overhangs effect the aesthetics of the buildings, it was important to observe precedents of overhangs of this nature in existing architecture. As figures 230-233 show, overhangs of the varying lengths are often found in existing New England architecture, without detriment to the integrity of the style.

Figure 230: Precedent of Cape with Multiple Window Overhangs

Figure 231: Precedent of Cape with Large Roof Overhang

Figure 232: Precedent of Colonial With Large Window Overhangs

Figure 233: Precedent of Saltbox with Window Overhang

Thermal Mass: For all models, the added thermal mass reduced the total conditioning costs. Adding thermal mass reduced the heating load, but increased the cooling load. As the level of energy efficiency increased, the effect of the thermal mass on both loads was reduced. For the IECC models increasing the slab thickness from 4” to 12” reduced annual conditioning costs by $140-$142. For the Passive House models, the same increase in thermal mass only resulted in a savings of $4-$6.

Figure 234: Stone Floor

Figure 235: Concrete Floor

Figure 236: Stone Chimney

Excel Calculator: Given the wide range of potential configurations and varying trends dictated by the different levels of energy efficiency, the excel calculator makes it easy for a user to see the operating cost for any specific configuration of variables. Additionally, it allows the user to quickly view the dynamic relationship of all the variables and see how the importance of one variable may be diminished as a result of the value of another variable.

Overview: For each architectural style, the IECC, Energy Star, and Energy Star-Passive House Average models showed a significant cost savings from implementing all of the passive solar design strategies. While the Passive House models did benefit from the passive solar features, the benefits were significantly smaller, and required significantly larger shading devices than the other models in order to prevent overheating. Given the already low conditioning costs of the Passive House models, adding the passive solar features may not make sense from a cost perspective. However, from an off the grid perspective, the passive solar features make these models significantly more hospitable in situations without the conventional means of heating and cooling.

APPENDIX A

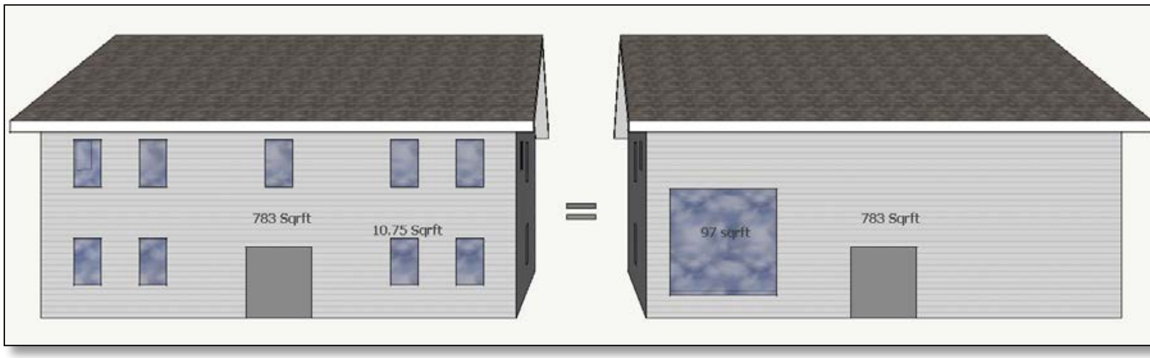
BUILDING DIMENSIONS

Colonial

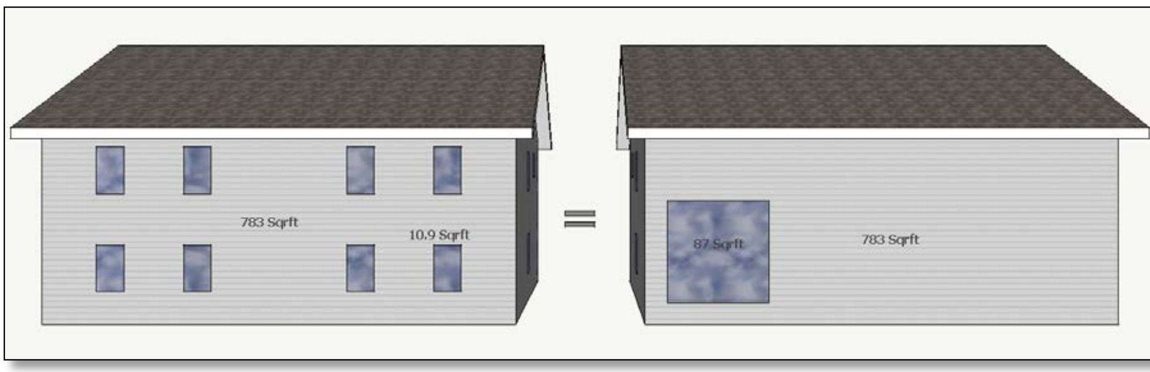
Window to Wall Ratios and Footprint Length to Width Ratio					
#	Front	Back	Side	Side	Length to Width Ratio
1	9	8	5	7	1.38
2	17	13	5	7	1.37
3	14	9	5	7	1.46
4	12	4	10	5	1.45
5	11	8	0	8	1.61
6	9	14	4	0	1.25
7	14	12	4	8	1.53
8	9	7	4	6	2.20
9	8	5	2	8	1.40
10	11	12	9	3	1.38
11	14	13	9	5	1.34
12	15	17	9	0	1.51
13	17	14	0	10	1.64
14	11	8	6	0	1.60
15	11	13	4	4	1.33
16	11	15	10	5	1.16
17	11	12	4	9	1.33
18	14	12	3	8	1.57
19	12	12	5	5	1.33
20	17	13	5	3	1.24
21	12	11	7	0	1.25
22	12	11	9	5	1.37
23	14	12	0	7	1.42
24	15	18	0	6	1.53
25	10	6	10	5	1.66
Avg.	12.4	11.16	5.16 (5.2)	5.24 (5.2)	1.45

A two story colonial with 2600 square feet, having a 1300 square foot footprint, with a length to width ratio of 1.45 is 43.5’ long by 30’ wide. With 8’ ceilings and one foot cavity space above each floor the exterior envelope walls are 18’ high. This gives the front and back an area of 783 square feet, and the sides an area of 540 square feet.

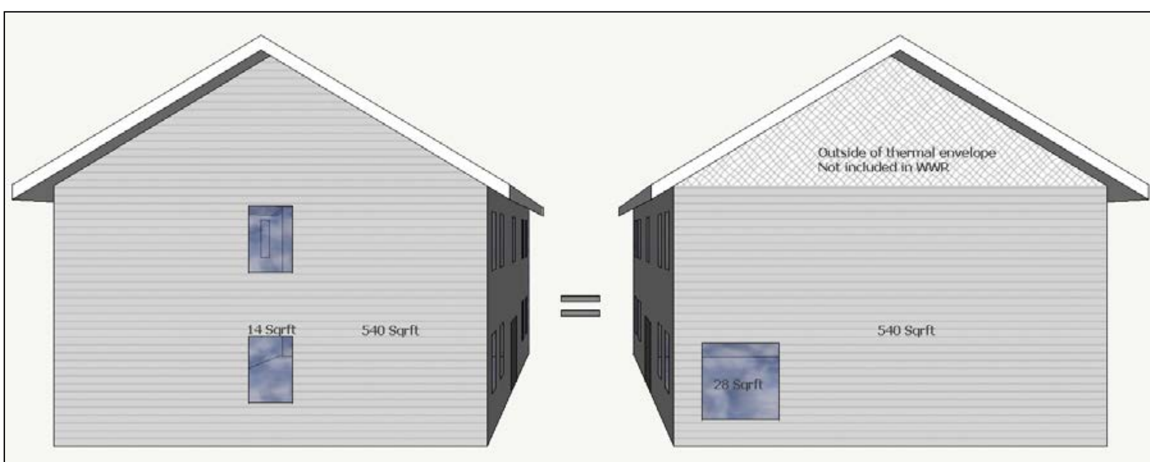
With an area of 783 square feet and a WWR of 12.4%, the front façade has 97 square feet of window area.



With an area of 783 square feet and a WWR of 11.6 %, the rear Façade has 87 square feet of window area.

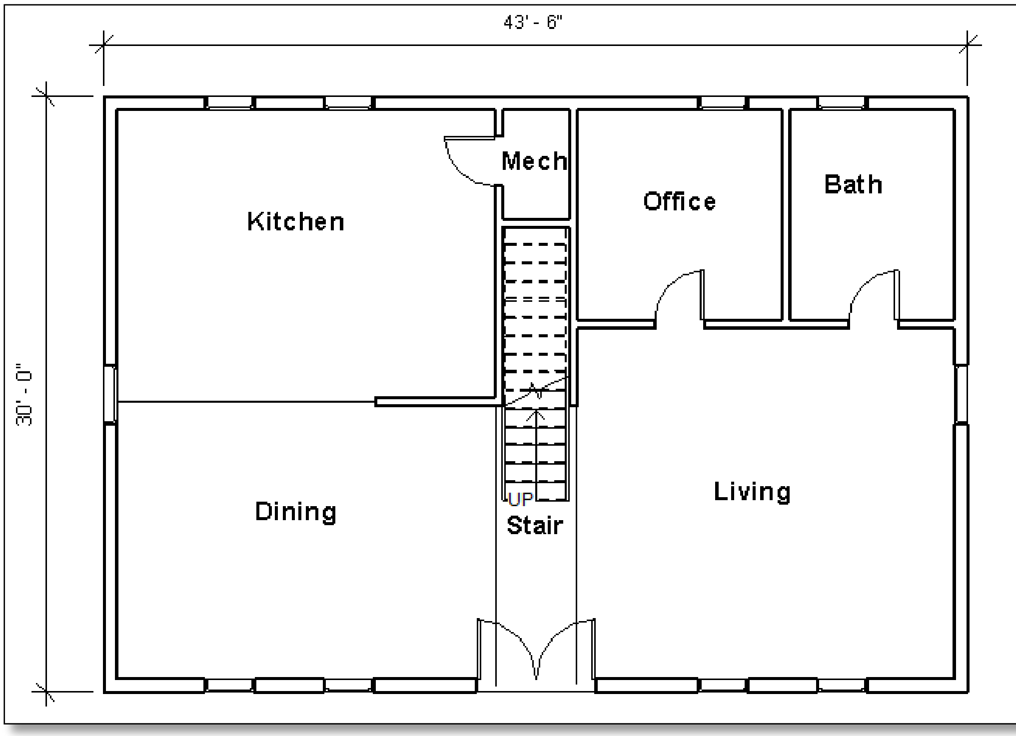


With an area of 540 square feet and a WWR of 5.2%, the side facades each have 28 square feet of window area.

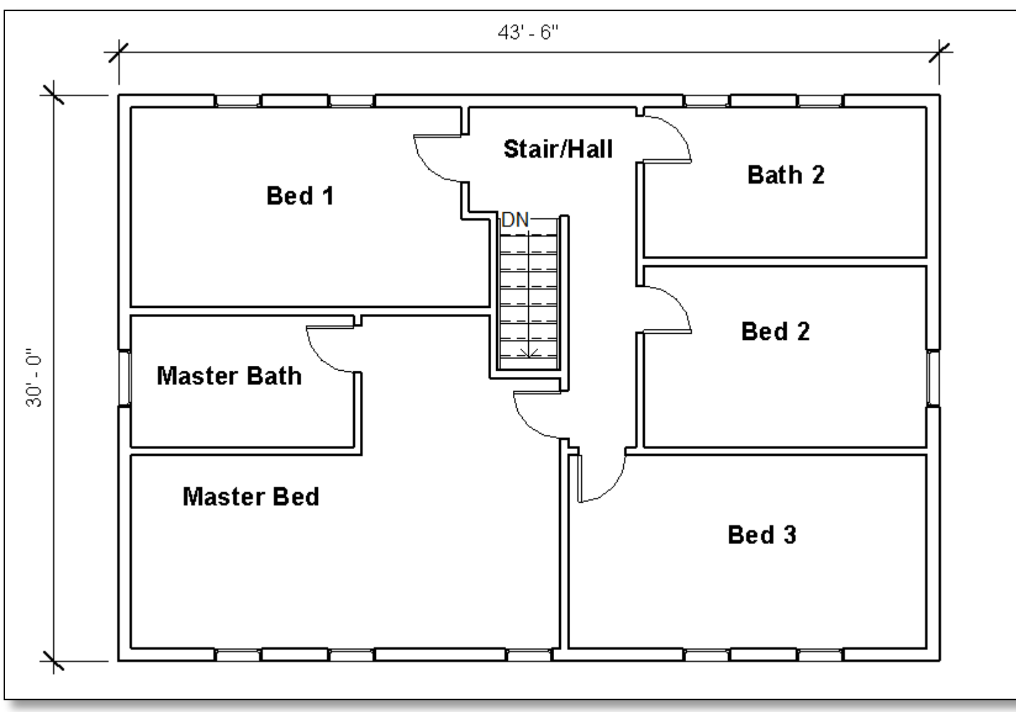


Revit Model:

First Floor



Second Floor

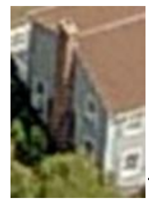


Sampled Houses

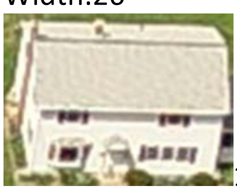
480 Middle Street
Length: 33’
Width: 24’

 8%
 5%
 9%
 7%

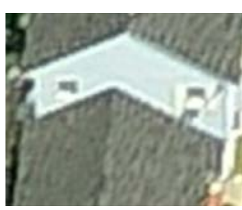
44 Blossom Street
Length: 37’
Width: 27’

 17%
 13%
 5%
 7%

350 Potwine Lane
Length:38’
Width:26’

 14%
 9%
 5%
 7%

94 Potwine Lane
Length: 35’
Width: 24’

 12%
 4%
 10%
 5%

591 West Street
Length:34’
Width:21’

 11%  0%  8%

651 South East Street
Length:30’
Width:24’

 9%  14%  4% 
0%

69 Dennis Lane
Length:40
Width:26

 14%  12%  4%  8%

159 Shays Street
Length:55’
Width:25’

 9%  7%  4%  6%

38 Hedgegrow Lane
Length:35’
Width:25’

 8%  5%  2%  8%

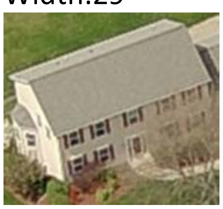
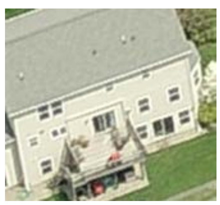
21 Hedgegro
Length:36’
Width:26’

 11%  12%  9%  3%

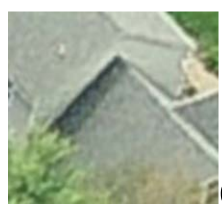
6 Arbor Way
Length:39
Width:29

 14%  13%  9%  5%

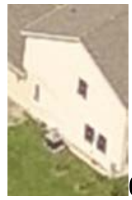
4 Teawattle Lane
Length:44’
Width:29’

 15%  17%  9%  0%

50 Kingman Road
Length: 46’
Width:28’

 17%  14%  0%  10%

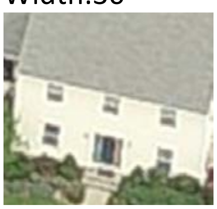
19 Owen Drive
Length:45’
Width:28’

 11%  8%  6%  0%

12 Owen Drive
Length: 40’
Width:30’

 11%  13%  4%  4%

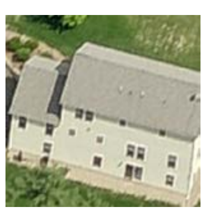
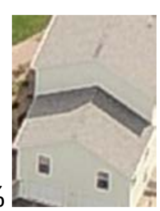
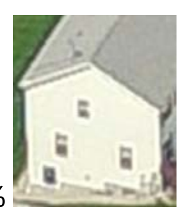
27 Rosemary Street
Length:35’
Width:30’

 11%  15%  10%  5%

10 Lantern Lane
Length:32’
Width:24’

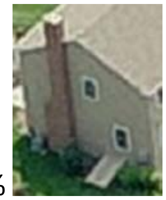
 11%  12%  4%  9%

16 Summerfield Road
Length: 44’
Width:28’

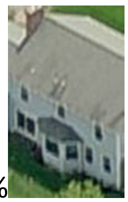
 14%  12%  3%  8%

20 Owen Drive

Length:40’
Width:30’

 12%  12%  5%  5%

44 Oakwood Circle
Length:41’
Width:33’

 17%  13%  5%  3%

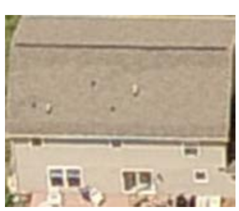
15 Valley Lane
Length:35’
Width:28’

 12%  11%  7%  0%

1 Poets Corner
Length:37’
Width:27’

 12%  11%  9%  5%

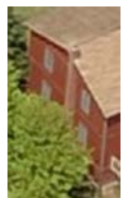
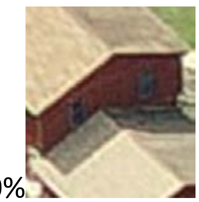
957 East Pleasant Street
Length:40’
Width:28’

 14%  12%  0%  7%

22 Emily Lane
Length:46
Width:30

 15%  18%  0%  6%

94 Mount Holyoke Drive
Length:50’
Width:30’

 10%  6%  10%  5%

Cape

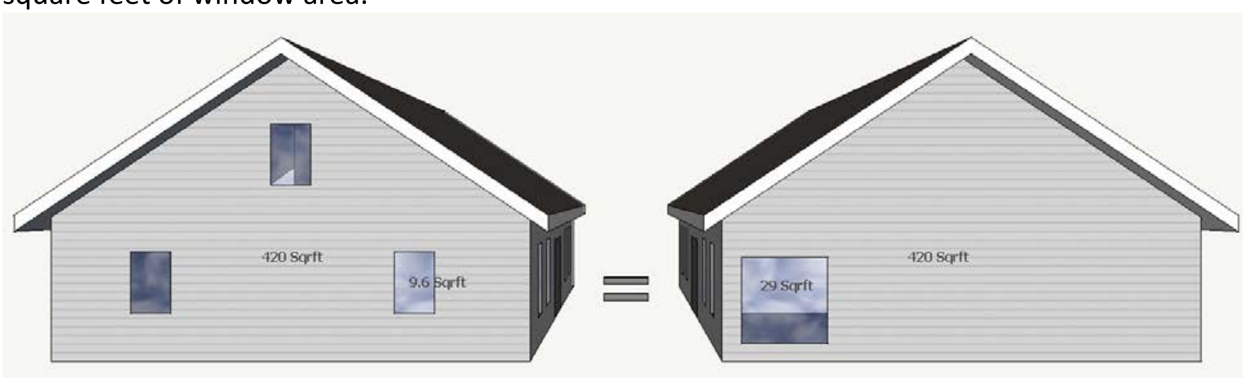
#	Front	Back	Side	Side	Length to Width Ratio
1	9	9	18	18	1.35
2	15	14	9	9	1.23
3	12	9	4	10	1.45
4	12	13	10	0	1.61
5	17	16	0	5	1.33
6	14	14	7	0	1.33
7	16	15	0	8	1.33
8	15	10	7	5	1.30
9	10	13	6	7	1.71
10	11	10	8	7	1.33
11	13	10	8	9	1.66
12	11	6	13	7	1.53
13	14	9	7	3	1.57
14	11	6	6	7	1.26
15	14	13	8	19	1.81
16	18	19	13	0	1.33
17	12	13	10	10	1.67
18	10	7	3	10	1.21
19	14	9	6	6	1.28
20	15	12	8	4	1.47
21	10	10	2	6	1.26
22	7	10	4	4	1.36
23	13	13	11	9	2.03
24	10	8	5	5	1.4
25	13	16	3	3	1.35
Avg.	12.64	11.36	7.04 (6.94)	6.84 (6.94)	1.44

A two story cape with a 1300 square foot footprint, with a length to width ratio of 1.44 is 43.5’ long by 30’ wide. With an 8’ ceiling and one foot cavity space above the first floor, and an 8’ cathedral ceiling second floor has a front and back an area of 392 square feet, and the sides an area of 420 square feet.

With an area of 392 square feet and a WWR of 12.64%, the front façade has 50 square feet of window area.

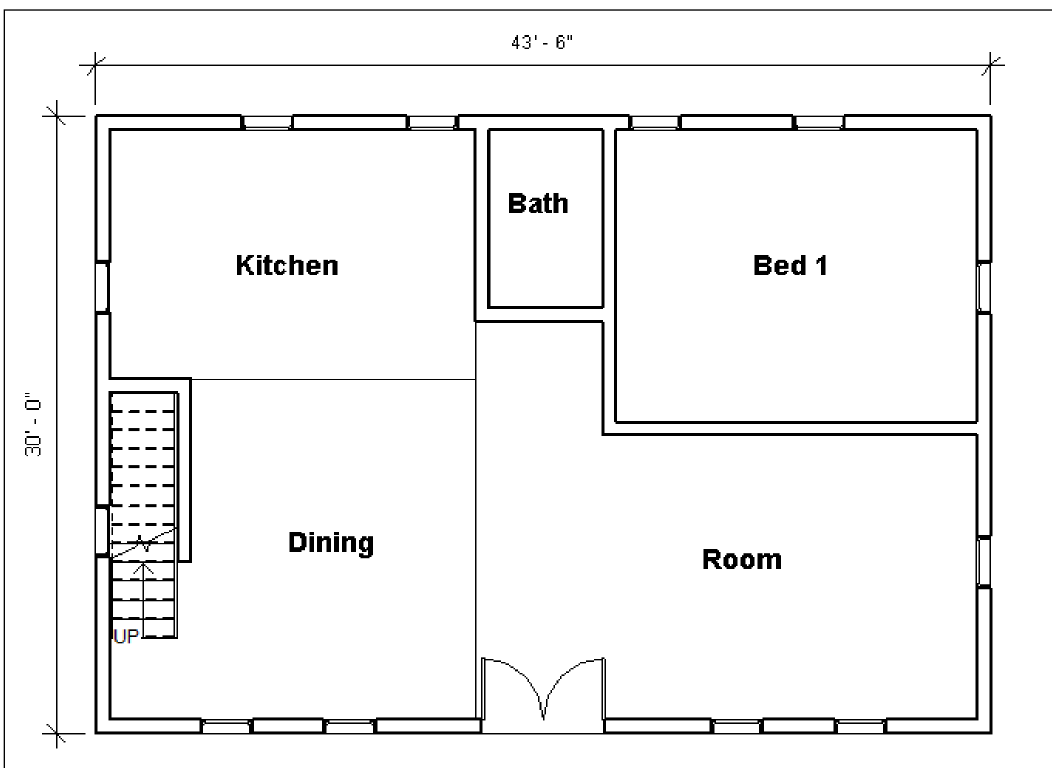
With an area of 392 square feet and a WWR of 11.36 %, the rear façade has 45 square feet of window area.

With an area of 420 square feet and a WWR of 6.94 %, the rear façade has 29 square feet of window area.

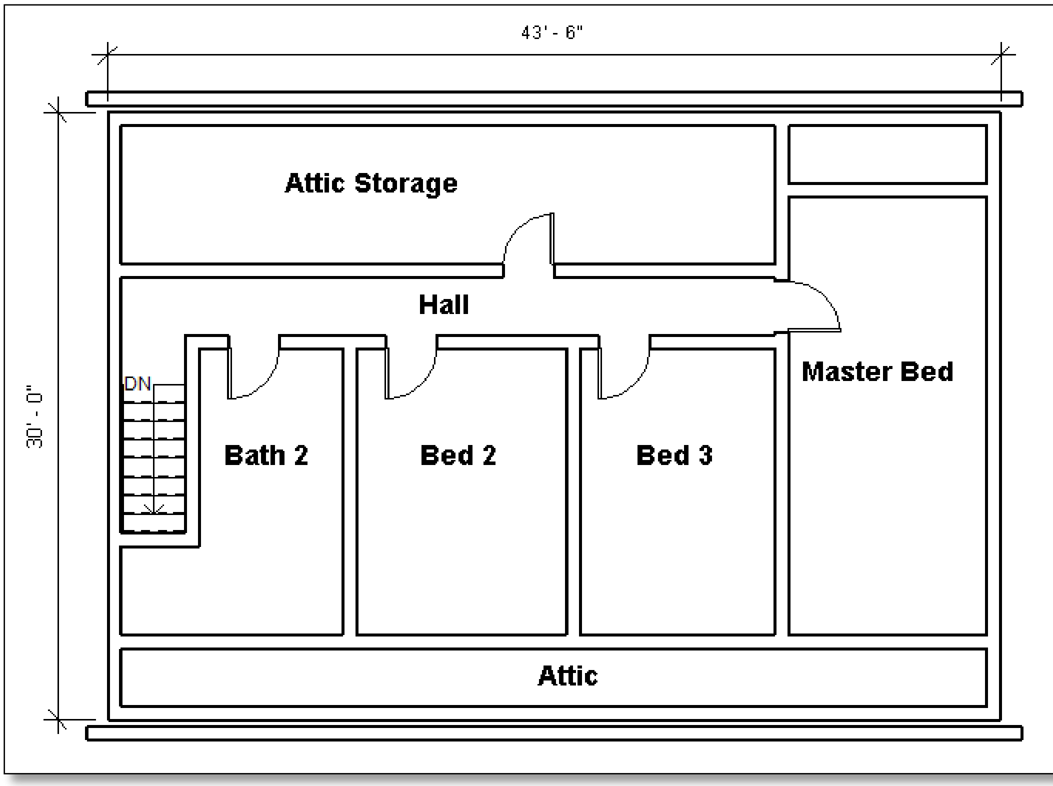


Revit Model:

First Floor



Second Floor



Sampled Houses

756 Southeast Street
Length:38’
Width:28’


9%


9%


18%


18%

25 Hedgegrow Lane
Length:32
Width:26


15%

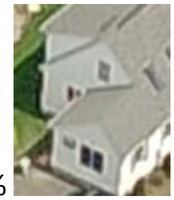

14%


9%


6%

17 Hedgegrow Lane

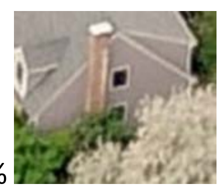
Length:35’
Width:24’

 12%  9%  4%  10%

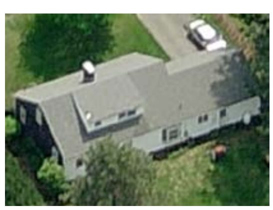
208 Rolling Ridge Road
Length:42’
Width:26’

 12%  13%  10%  0%

8 Tuckerman Lane
Length:40’
Width:30’

 17%  16%  0%  5%

129 Harlow Drive
Length: 40’
Width:30’

 14%  14%  7%  0%

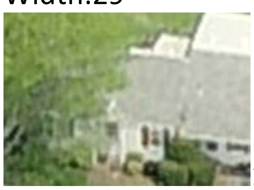
19 Van Meter Drive
Length: 40
Width:30

 16%  15%  0%  8%

155 Grantwood Drive
Length:30’
Width:23’

 15%  10%  7%  5%

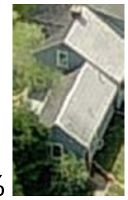
1204 SouthEast Street
Length:52’
Width:29’

 10%  13%  6%  7%

81 East Hadley Road
Length:32’
Width:24’

 11%  10%  8%  7%

48 Stanley Street
Length:50’
Width:30’

 13%  10%  8%  9%

12 Willow Lane
Length:40’
Width:26’

 11%  6%  13%  7%

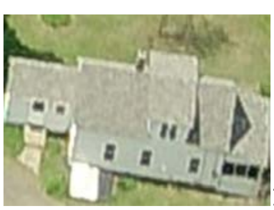
173 Stanley Street
Length:44’
Width:28’

 14%  9%  7%  3%

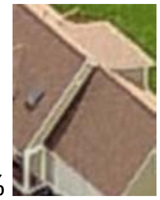
1139 North Pleasant Street
Length:33’
Width:26’

 11%  6%  6%  7%

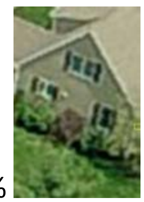
Bay Road
Length:40’
Width:22’

 14%  13%  8% 
19%

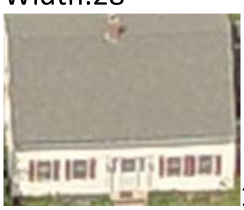
43 Summerfield Street
Length:40
Width:30

 18%  19%  13%  0%

173 Wildflower Drive
Length:47’
Width:28’

 12%  13%  10%  10%

332 west Street
Length: 34’
Width:28’

 10%  7%  3% 
10%

290 West Street
Length:32’
Width:25’

 14%  9%  6% 
6%

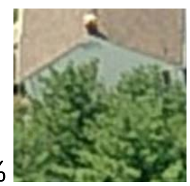
8 Norwottock Circle
Length:50’
Width:34’

 15%  12%  8%  4%

17 Pondview
Length:33’
Width:26’

 10%  10%  2%  6%

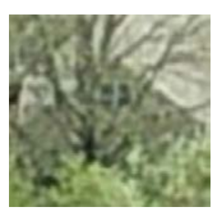
156 Pomeroy Court
Length:41’
Width:30’

 7%  10%  4%  4%

28 Carriage Lane
Length:55’
Width:27’

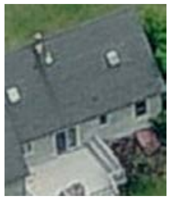
 13%  13%  11%  9%

79 Salem Street
Length:35’
Width:25’

 10%  8%  5% 

5%

28 Whippletree Lane
Length:38’
Width:28’

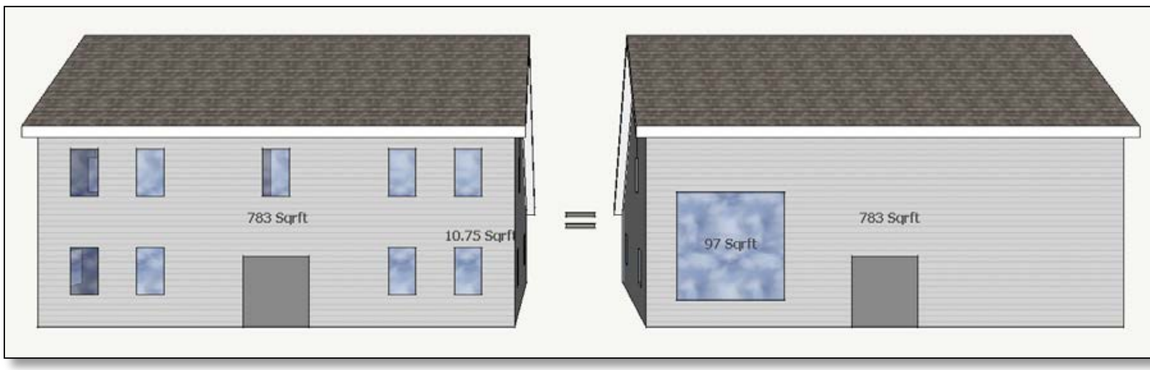
 13%  16%  3%  3%

Saltbox

Window to Wall Ratios and Footprint Length to Width Ratio					
#	Front	Back	Side	Side	Length to Width Ratio
1	9	9	5	7	1.38
2	17	14	5	7	1.37
3	14	9	5	7	1.46
4	12	13	10	5	1.45
5	11	16	0	8	1.61
6	9	14	4	0	1.25
7	14	15	4	8	1.53
8	9	10	4	6	2.20
9	8	13	2	8	1.40
10	11	10	9	3	1.38
11	14	10	9	5	1.34
12	15	6	9	0	1.51
13	17	9	0	10	1.64
14	11	6	6	0	1.60
15	11	13	4	4	1.33
16	11	19	10	5	1.16
17	11	13	4	9	1.33
18	14	7	3	8	1.57
19	12	9	5	5	1.33
20	17	12	5	3	1.24
21	12	10	7	0	1.25
22	12	10	9	5	1.37
23	14	13	0	7	1.42
24	15	8	0	6	1.53
25	10	16	10	5	1.66
Avg.	12.4	11.36	5.16 (5.2)	5.24 (5.2)	1.45

Given the similarities to the Colonial, the front and sides of the Saltbox will use the Colonial values. Because the rear of the Saltbox is only one story the rear values from the Cape will be used.
A two story Saltbox with 2600 square feet, having a 1300 square foot footprint, with a length to width ratio of 1.45 is 43.5' long by 30' wide. With 8' ceilings and one foot cavity space above each floor the exterior envelope walls are 18' high. This gives the front an area of 783 square feet, the back an area of 392' and the sides an area of 495 square feet.

With an area of 783 square feet and a WWR of 12.4%, the front façade has 97 square feet of window area.

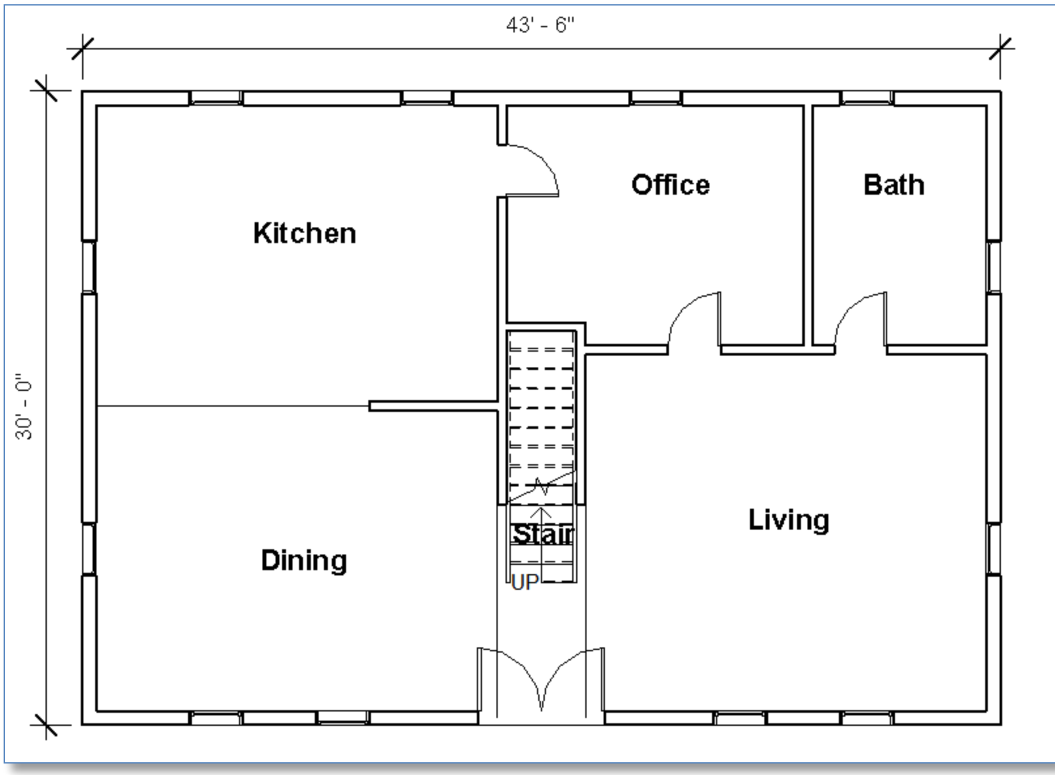


With an area of 392 square feet and a WWR of 11.36 %, the rear Façade has 45 square feet of window area.

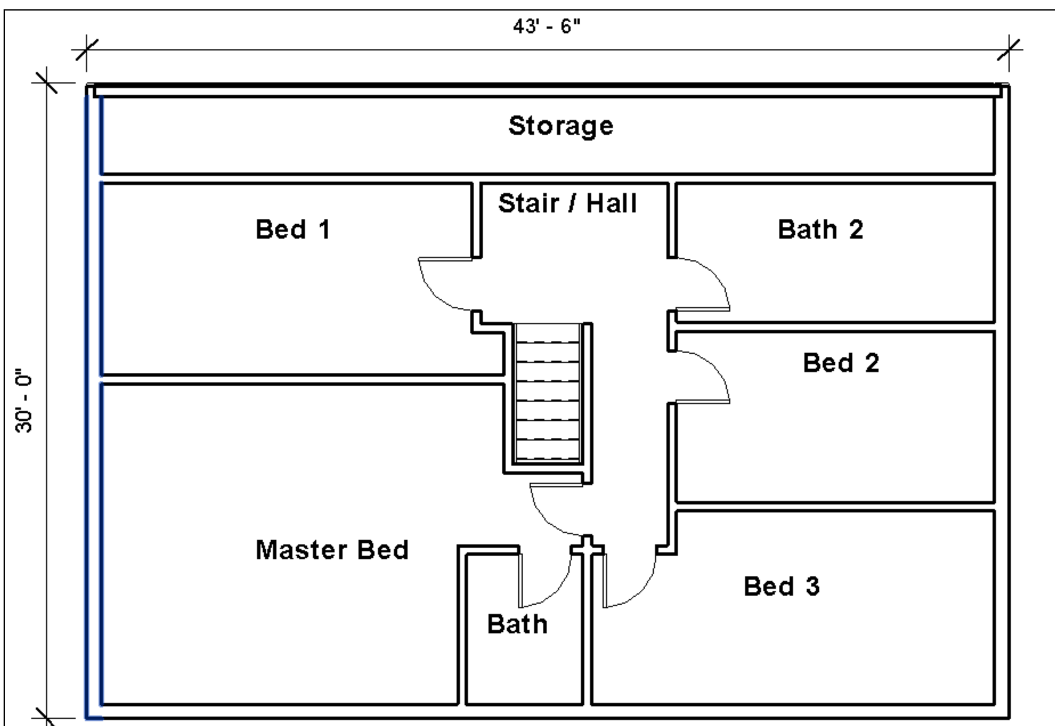
With an area of 495 square feet and a WWR of 5.2%, the side facades each have 26 square feet of window area.

Revit Model:

First Floor



Second Floor



APPENDIX B

INPUT VALUES

Activity		
Activity Template		
Template	Domestic Circulation	
Sector	Residential Spaces	Attic= Semi-exterior Un-conditioned
Zone Multiplier	1	
Include Zone in Thermal Calculations	Active	Attic = Active
Include zone in daylighting calculations	Active	Attic=Inactive
Occupancy		
Density people/ft^2**	0.00153 (4 people)**	
Schedule	Dwell_Domcirculation_Occ	
Metabolic		
Activity**	Standing Relaxed (430 Btu/h/person**	
Factor (Men=1, Women=0.85, Children =0.75	0.90	
Winter Clothing (clo)	1.0	
Summer Clothing (clo)	0.50	
Holidays		
Holidays	Inactive	
Domestic Hot Water (DHW)		
Consumption Rate (gal/ft^2/day) **	NA (De-activated in HVAC tab) **	
Environmental Controls		
Heating Setpoint**	72°f (no setback) **	(IECC 2009, table 405.5.2[1])
Cooling Setpoint**	75° (no setback) **	(IECC 2009, table 405.5.2[1])
Humidity Control**	NA (De-activated in HVAC tab) **	
Ventilation Setpoint Temperatures		
Natural Vent Cooling (°f)	71.6	
Delta T (deltaF)	-90.0	
Minimum fresh air	Controlled in HVAC tab	
Lighting		

Lighting Target Illuminance (Foot-candles)	9.29	
Default display lighting density	0	
Computers		
Computers	Inactive	
Office Equipment		
Gain (W/ft^2)	0.1459	
Schedule	Dwell_DomCirculation_Equip	
Radiant fraction	0.200	
Miscellaneous		
Miscellaneous	Inactive	
Catering		
Catering	Inactive	
Process		
Process	Inactive	
Location		
Weather File	Chicopee Falls, MA	

Construction		
Construction Template		
Template	IECC-2000,Lightweight	
Construction		
External Walls*	3/4" Cedar Clapboard- 5/8" OSB- Required thickness of Cellulose- 5/8" Gypsum Board*	Use U-Factor from respective EE level, reflected in insulation thickness*
Flat Roof	NA	
Pitched roof occupied*	1/4" Asphalt shingles- 5/8" OSB-Required thickness of Cellulose- 5/8" Gypsum board*	Use U-Factor from respective EE level, reflected in insulation thickness*
Pitched Roof Unoccupied**	1/4" Asphalt shingles- 5/8" OSB**	
Internal Partitions**	5/8" Gypsum board- 3 ½" Air gap – 5/8" Gypsum board**	
Semi-Exposed		
Semi-exposed walls	NA	
Semi-exposed Ceiling*	Required thickness of cellulose- 5/8"Gypsum*	Use U-Factor from respective EE level, reflected in insulation

		thickness*
Semi-exposed floor	NA	
Floors		
Ground floor*	Required thickness of Expanded Polystyrene (EPS)-4" poured concrete*	Use U-Factor from respective EE level, reflected in insulation thickness*
External floor	NA	
Internal floor**	5/8" OSB-3/4" Maple/Oak**	
Sub Surfaces		
Walls	NA	
Internal	NA	
Roof	NA	
External door*	Metal door with required thickness of EPS core*	Use U-Factor from respective EE level, reflected in insulation thickness*
Internal door	Wooden door	
Internal Thermal Mass		
Construction**	Concrete**	Sized accordingly when thermal mass is manipulated**
Component Block		
Component block type	Ground	
Shades and Reflects	Active	
Material	Earth, common	
Maximum transmittance	0.0	
Transmittance schedule	on	
Surface Convection		
Inside convection algorithm (Heating, Cooling, Simulation)	TARP	
Outside convection algorithm(Heating, Cooling, Simulation)	DOE-2	
Airtightness		
Model infiltration	Active	
Constant rate (AC/H@50 Pa*	Dictated by EE level*	

Openings		
Glazing Template		
Template	IECC-2000	

External Windows		
Glazing type		
Definition method**	Simple**	
Solar Heat Gain Coefficient**	SHGC=0.4 **	(IECC 2009, table 405.5.2[1])
Solar Heat Gain Coefficient**	SHGC=6.5 is applied to Southern Façade, once the model is oriented properly**	
Light transmission**	0.7**	
U-value*	Dictated by EE level*	
Dimensions**	NA (Customized in designs) **	
Reveal		
Outside reveal depth	0.0”	
Inside reveal depth	0.0”	
Inside reveal	0.0”	
Frame and Dividers		
Has a frame/dividers	Active	
Construction	Painted wooden window frame	
Dividers		
Type	Divided lite	
width	0.75	
Horizontal dividers	1	
Vertical dividers	1	
Outside projection	0.0”	
Inside projection	0.0”	
Glass edge-centre conduction ratio	1.0	
Frame		
Frame width	1.575”	
Frame inside projection	0.0”	
Frame outside projection	0.0”	
Glass edge –centre conduction ratio	1.0	
Shading		
Window shading	Inactive	
Local shading	Inactive	Sized accordingly when shading is manipulated**
Internal Windows		
Internal windows	NA	

Roof windows/Skylights		
Roof windows/skylights	NA	
Doors		
External		
Auto generate	Inactive (customized in designs)	
Internal		
Auto generate	Inactive (customized in designs)	
Percent area door opens	50%	
Percent time door is open	5%	
Operation schedule	Dwell_DomCirculation_Occ	
Vents		
Internal	NA	

Lighting		
Lighting Template		
Template	IECC-2000	
General Lighting		
General Lighting	Active	
Lighting energy (W/ft^2/foot-candle)	0.0340	
Schedule	Dwell_DomCirculation_Light	
Luminaire type	Suspended	
Radiant fraction	0.420	
Visible fraction	0.180	
Convective fraction	0.400	
Lighting control		
Lighting control**	Inactive**	
Task and display lighting		
Task and display lighting	Inactive	
Exterior Lighting		
Exterior Lighting	Inactive	

HVAC		
HVAC Template		
Template	Split + separate mechanical ventilation	
System availability schedule**	On**	
Mechanical Ventilation		
Mechanical Ventilation	On for Passive House EE	

	level Off for all other EE levels (Following values only applicable to Passive House model)	
Outside air definition method	1-By zone	
Outside air (ac/h**	0.350**	
Min AHY outside air requirement Schedule**	On**	
Fans		
Fan operation mode**	2-Cycling**	
Pressure rise in (H20)	1.607	
Total efficiency (%)	70	
Fan in air (%)	100	
Economiser		
Type	1-none	
Heat Recovery		
Heat Recovery	Active	
Heat recover type	1-Sensible	
Sensible heat recovery effectiveness	0.70	
Heating setpoint temperature (°f)	59.00	
Operation Schedule	on	
Heating		
Heating	Active	
Unitary heating fuel	2-Natural gas	
Heating coil CoP**	0.80**	
Unitary distribution loss	5.0	
Operation schedule	Dwell_DomCirculation_Heat	
Cooling		
Cooled	Active	
Unitary cooling fuel	1-Electricity from grid	
Unitary cooling CoP**	2.5**	
Unitary distribution loss	5.0	
Operation schedule	Dwell_DomCirculation_Cool	
Humidity Control		
Humidification	Inactive	
Dehumidification	Inactive	
DHW		
DHW	Inactive	
Natural Ventilation		
Natural Ventilation	Inactive	

-Thermal bridging from framing elements are previously calculated, and reflected in the Effective U-factors.
-Black text is data that is unchanged from template
* data that is changed from the specific to EE level
**Blue text is data that is changed from template, but constant across EE levels

APPENDIX C

EXISTING PASSIVE HOUSE VALUES IN NORTHEAST

#1025 Beaton Residence

Location: Shrewsbury, MA

Exterior Wall: 14” TJI with blown Cellulose (R-41)

Floor: 10” EPS under 4” Concrete (R-36)

Roof: 30” of cellulose in open web truss (R-99)

Window: Accurate Dorwin

Infiltration: ACH50=0.49

#1036 Cleveland Farm

Location: MA

Exterior Wall: 12” (2” Polyurethane spray Foam, 10” Dense pack Cellulose) (R-41)

Floor: 8” EPS under Slab (R-30)

Roof: 14” Blown Cellulose, 2” Polyurethane spray foam (R-54)

Window: Triple pane low e argon filled

Infiltration: ACH50= NA

#1066 EcoCor House

Location: Knox, ME

Exterior Wall: R-58 Assembly

Floor: R-54

Roof: R-80

Window: Intus Windows Guardian. U-0.106

Infiltration: ACH50= 0.28

HRV:92% efficient, 0.25W/cfm

<u>#1027 Falmouth</u>

Location: Falmouth, MA

Exterior Wall: NA

Floor: Concrete slab with 4” XPS and 16” Dense cellulose underneath (R-77)

Roof: 30” of blown cellulose (R-99)

Window: NA

Infiltration: ACH50= 0.54

<u>#1023 Habitat for Humanity, Charlotte, Vermont</u>

Location: Charlotte, VT

Exterior Wall: 2x6 wall with dense pack cellulose, 6” polyisocyanurate (R-47)

Floor: 12” XPS under 4” Concrete Slab (R-56)

Roof: 24”Blown Cellulose (R-79)

Window: Thermotech Fiberglass

Infiltration: ACH50=0.42

<u>#1059 Jackman Residence</u>

Location: Stowe, VT

Exterior Wall: 7.25” cellulose, 6”Polyisocyanurate (R-52)

Floor: 4”concrete slab on 6” of XPS (R-30)

Roof: 20” of Cellulose (R-65)

Window: Triple pane Pilkington Low E

Infiltration: ACH50= 0.46

<u>#1028 The GO Home</u>

Location: Belfast, ME

Exterior Wall: SIPS NA

Floor: 8” EPS under 5”concrete (R-35)

Roof: 25” Sprayed Cellulose (R-82)

Window: Thermotech Fiberglass

Infiltration: ACH50= 0.50

Average Effective Wall R Value= R-48

Average Effective Floor R Value= R-45

Average Effective Ceiling R Value= R-80

Average Infiltration ACH50 = 0.45

-Wall Effective R values account for a 15 percent bridging for the cavity insulation, as well as cedar clapboards, 5/8” OSB sheathing and 5/8” Gypsum board on the interior, as will be used in subsequent models.

Ceilings – Effective R values account for a 10 percent bridging for the first 11.25”, the remaining insulation is continuous, as well as 5/8” Gypsum board on the interior.

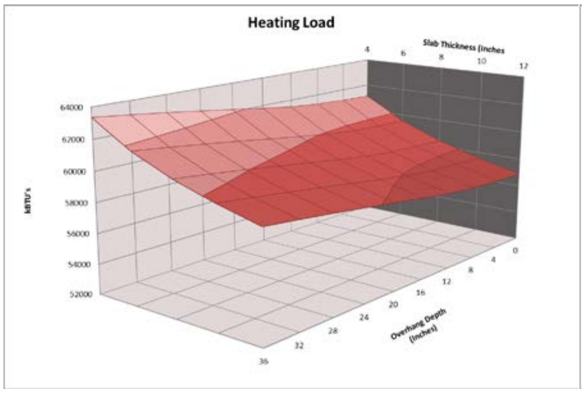
APPENDIX D

MODEL OUTPUT

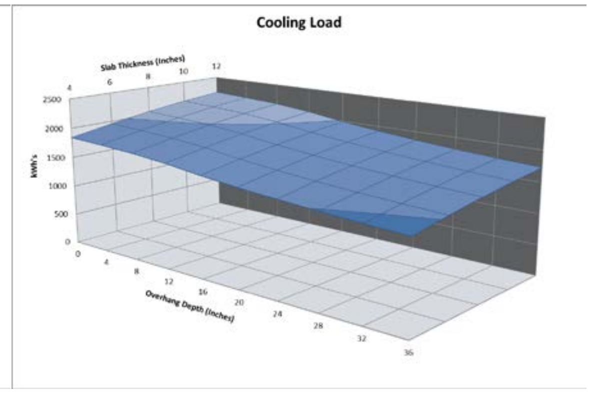
Colonial

IECC

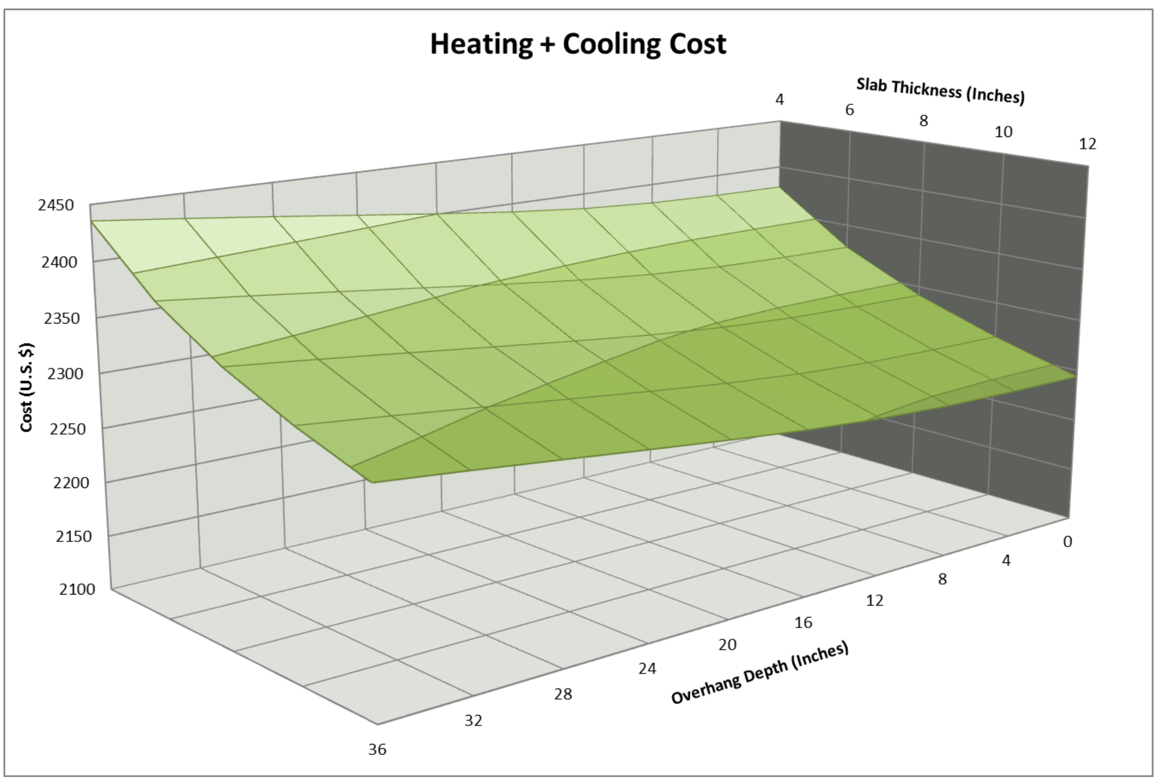
<u>12.4 WWR:</u>



Colonial IECC 12.4 WWR Heating Load



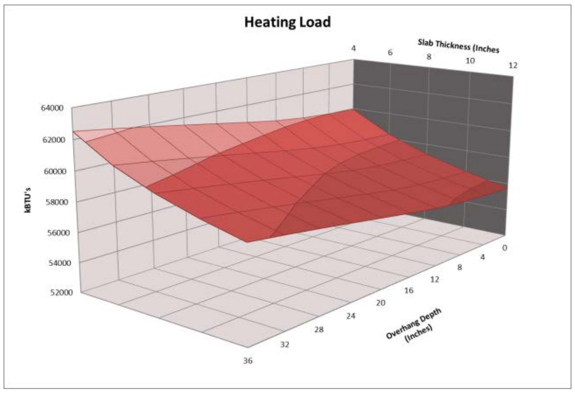
Colonial IECC 12.4 WWR Cooling Load

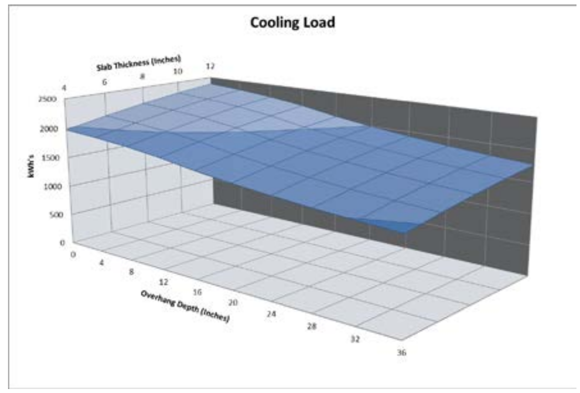


Colonial IECC 12.4 WWR Heating and Cooling Cost

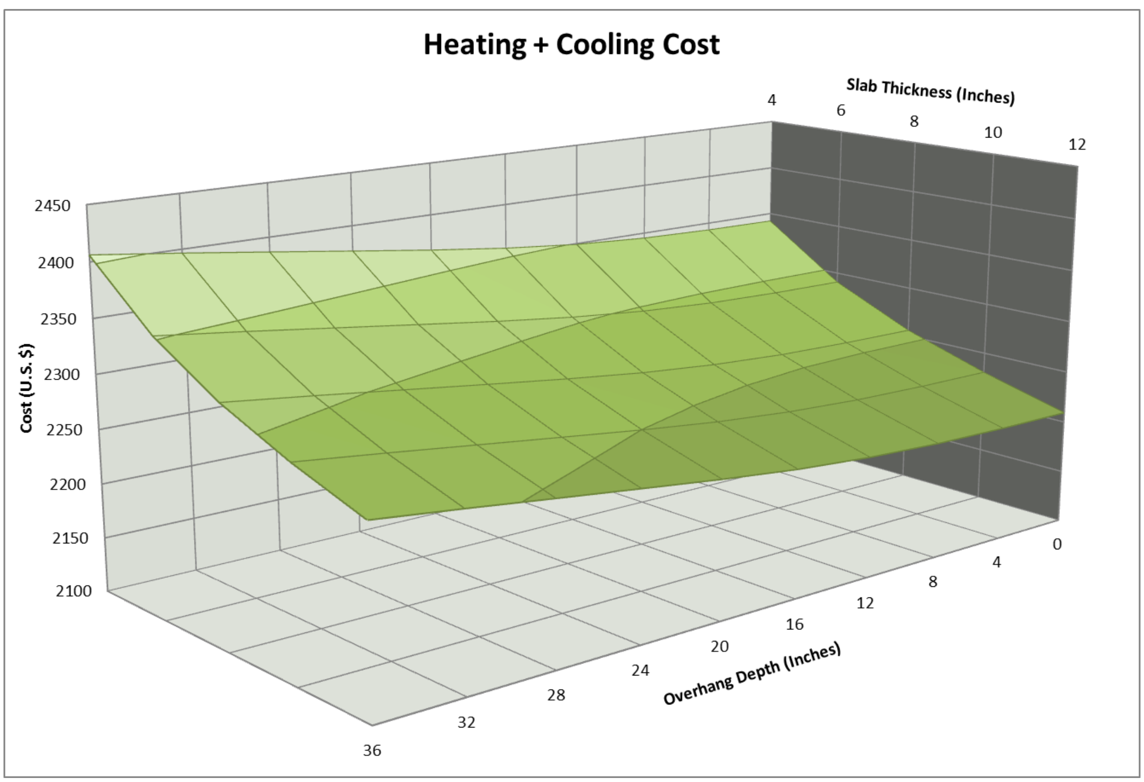
With a WWR of 12.4 the minimum cost of $2,243 occurs with a 12” Slab and a 0” Overhang.

15.1 WWR:





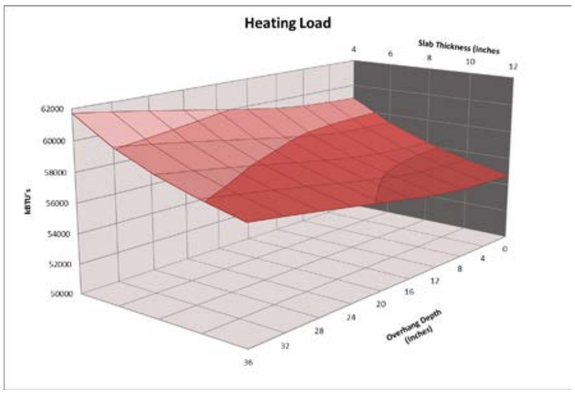
Colonial IECC 15.1 WWR Heating Load Colonial IECC 15.1 WWR Cooling Load

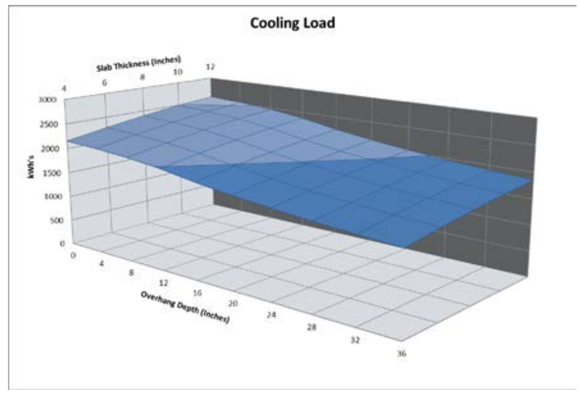


Colonial IECC 15.1 WWR Heating and Cooling Cost

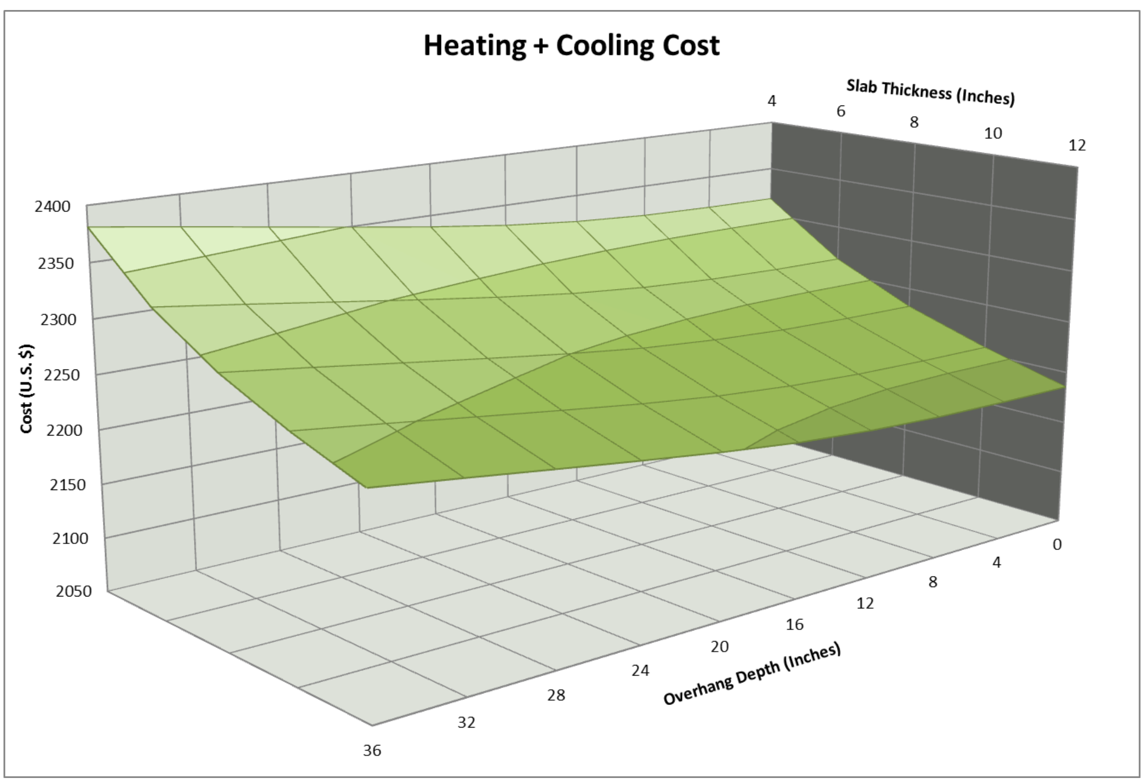
With a WWR of 15.1 the minimum cost of $2,209 occurs with a 12” Slab and a 0” Overhang.

17.8 WWR:





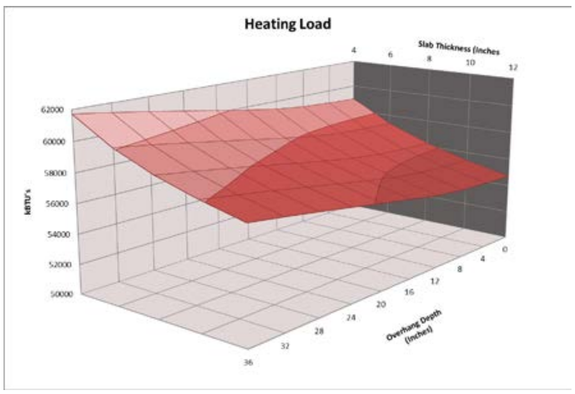
Colonial IECC 17.8 WWR Heating Load Colonial IECC 17.8 WWR Cooling Load

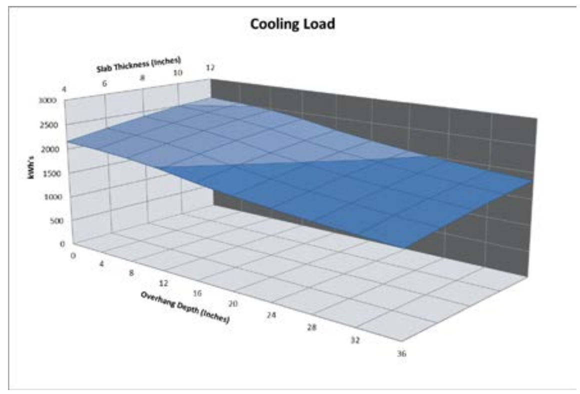


Colonial IECC 17.8 WWR Heating and Cooling Cost

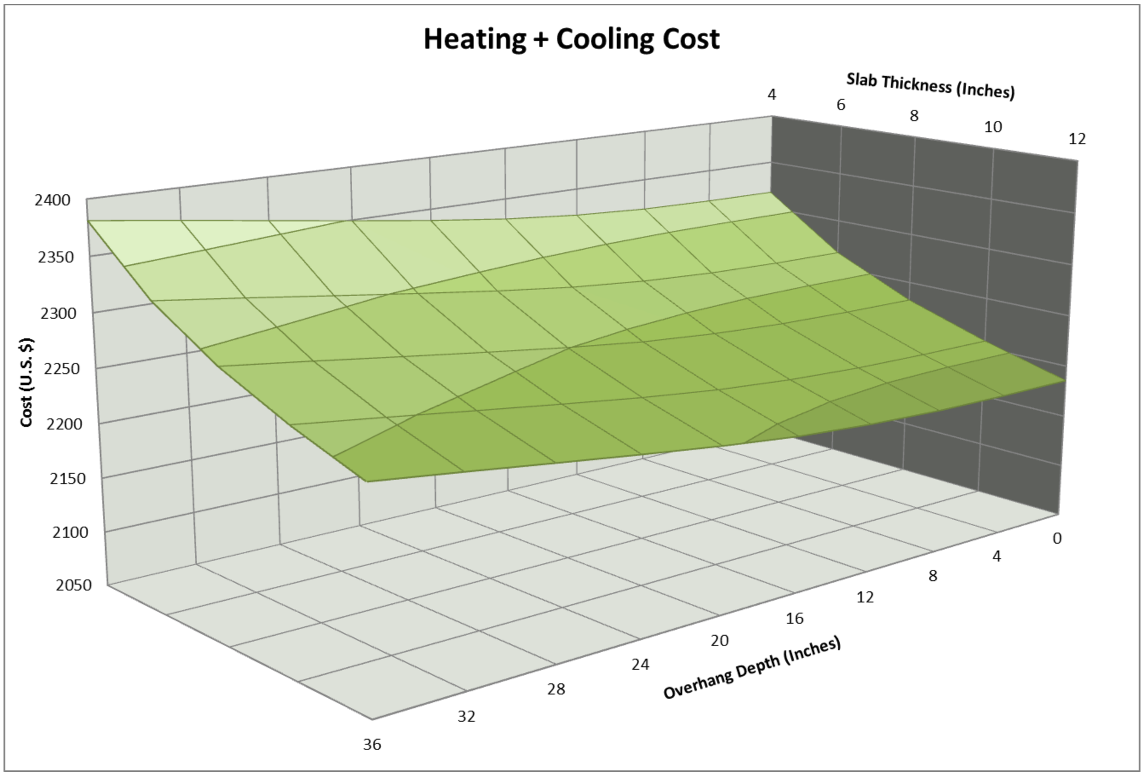
With a WWR of 17.8 the minimum cost of $2,185 occurs with a 12" Slab and a 0" Overhang.

20.6 WWR:





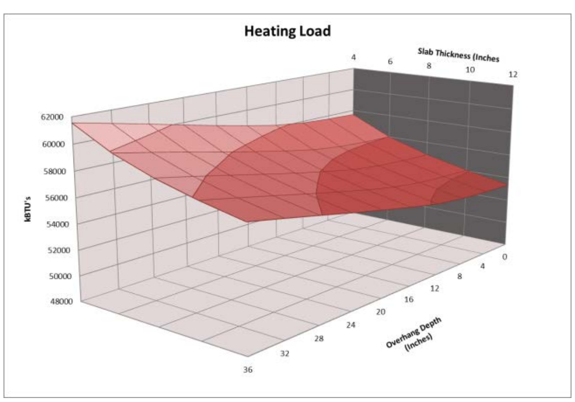
Colonial IECC 20.6 WWR Heating Load Colonial IECC 20.6 WWR Cooling Load

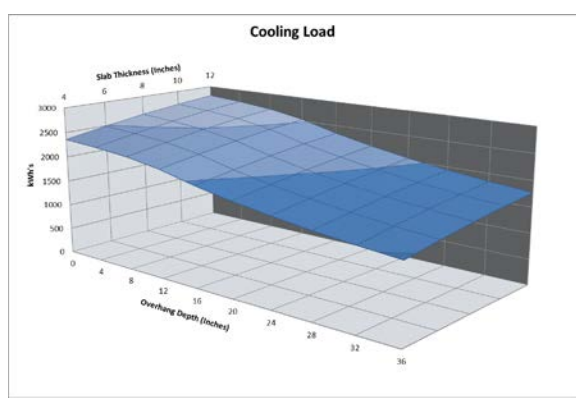


Colonial IECC 20.6 WWR Heating and Cooling Cost

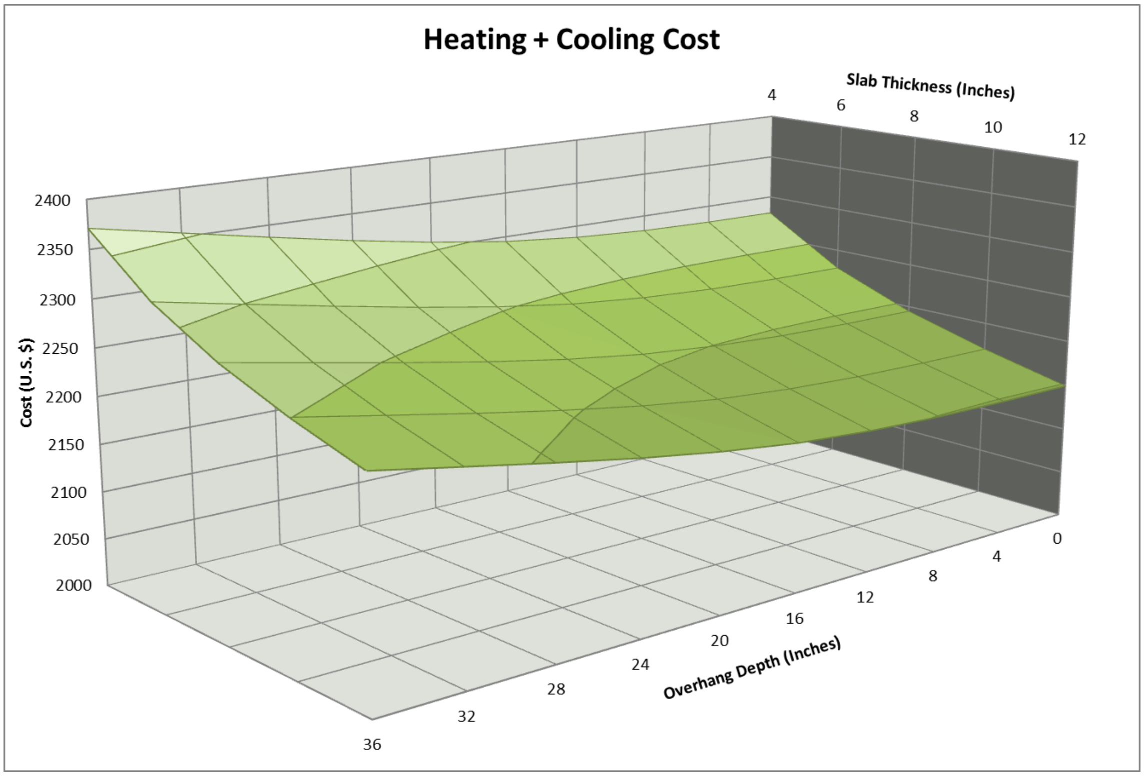
With a WWR of 20.6 the minimum cost of $2185 occurs with a 12” Slab and a 0” Overhang.

23.3 WWR:





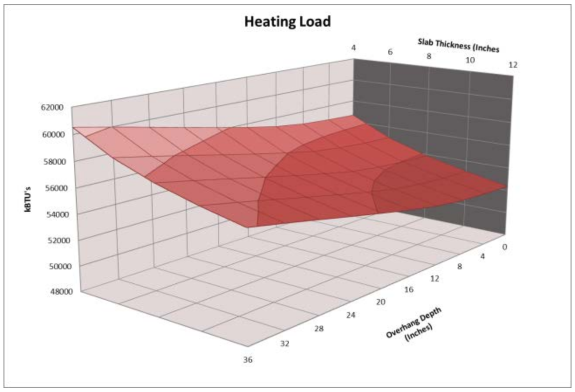
Colonial IECC 23.3 WWR Heating Load Colonial IECC 23.3 WWR Cooling Load

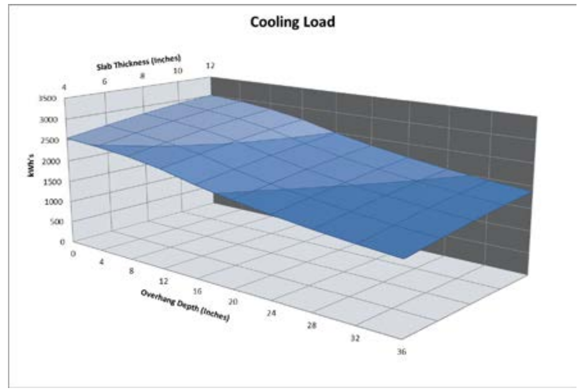


Colonial IECC 23.3 WWR Heating and Cooling Cost

With a WWR of 23.3 the minimum cost of $2,148 occurs with a 12” Slab and a 4” Overhang.

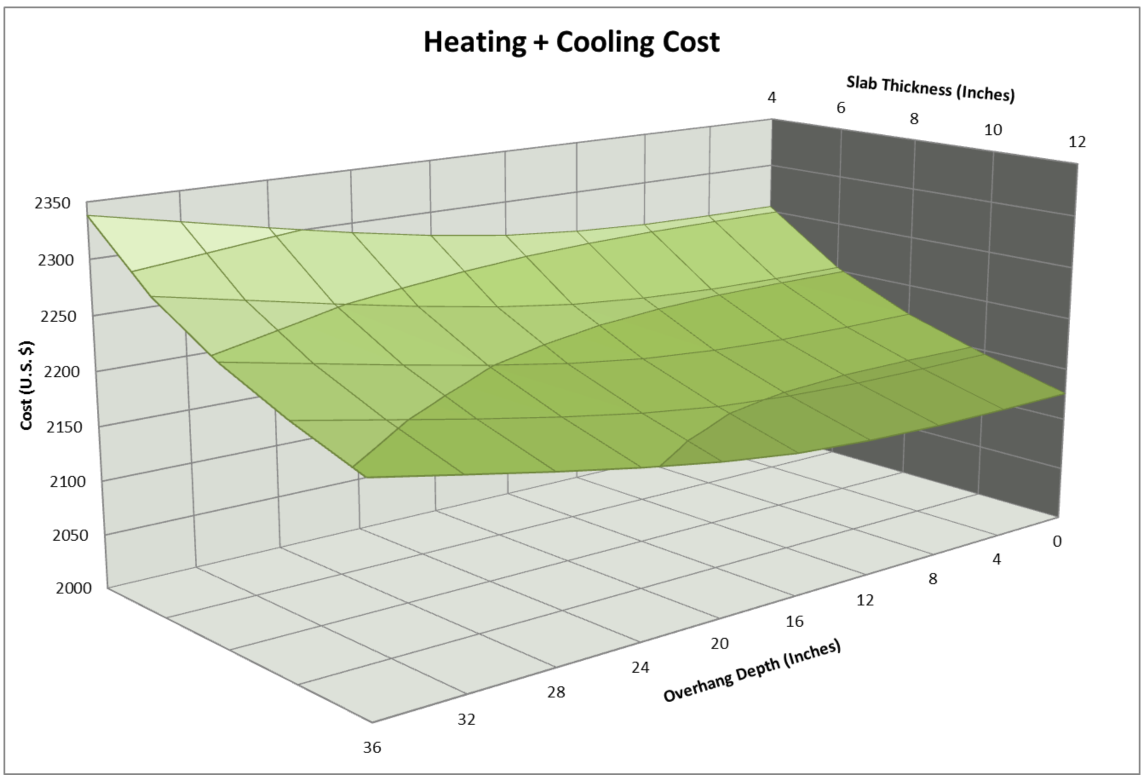
26 WWR:





Colonial IECC 26 WWR Heating Load

Colonial IECC 26 WWR Cooling Load

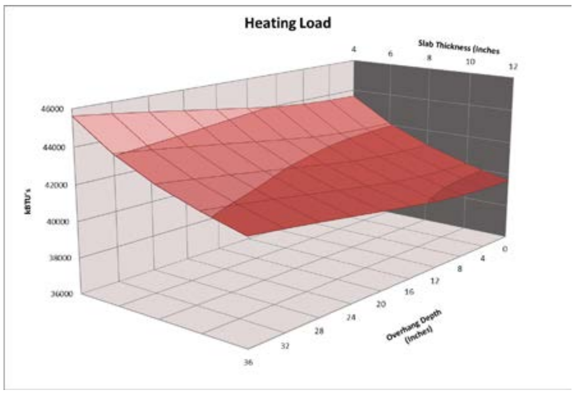


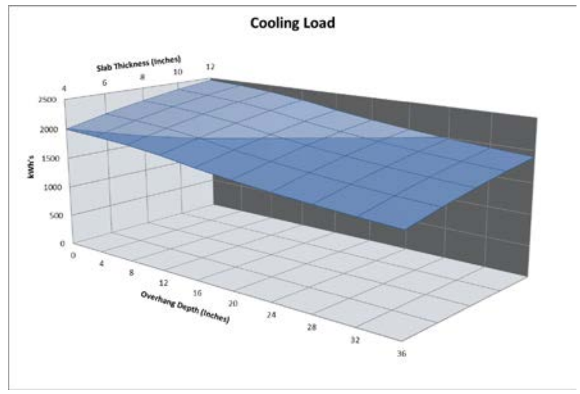
Colonial IECC 26 WWR Heating and Cooling Cost

With a WWR of 26 the minimum cost of $2,124 occurs with a 12" Slab and a 4" Overhang.

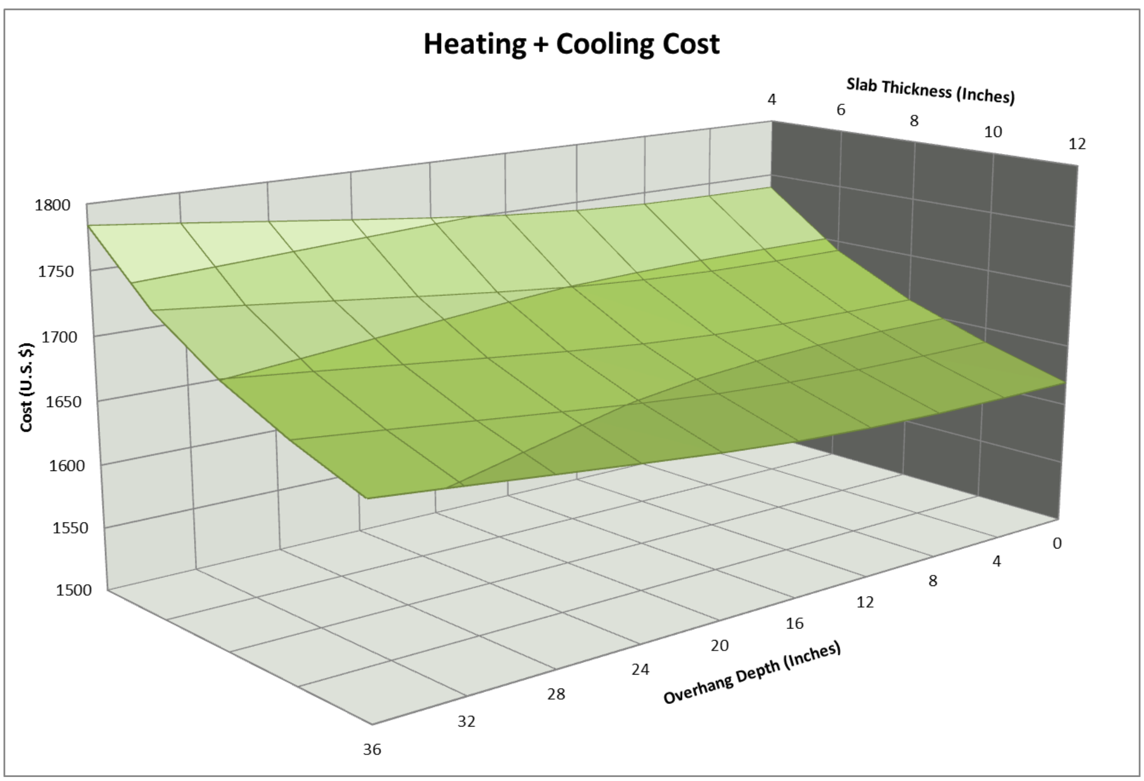
Energy Star

<u>12.4 WWR:</u>





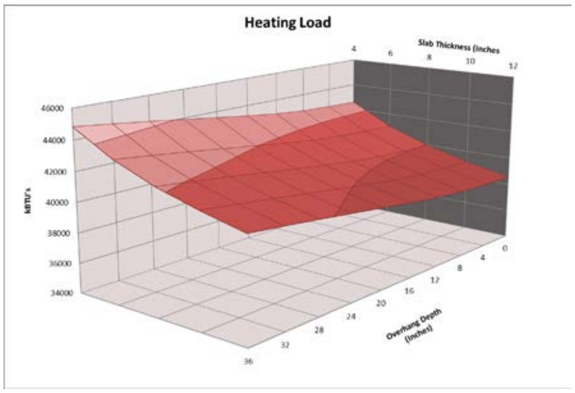
Colonial Energy Star 12.4 WWR Heating Load Colonial Energy Star 12.4 WWR
Cooling Load

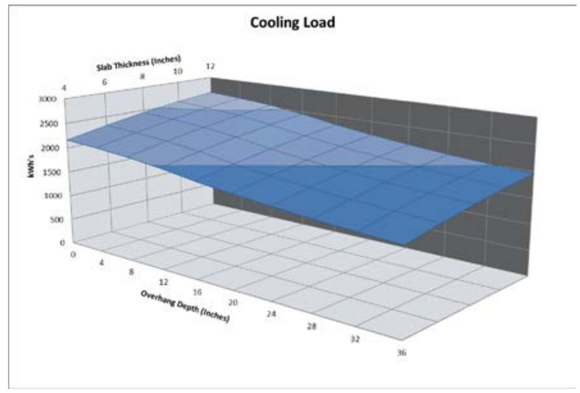


Colonial Energy Star 12.4 WWR Heating and Cooling Cost

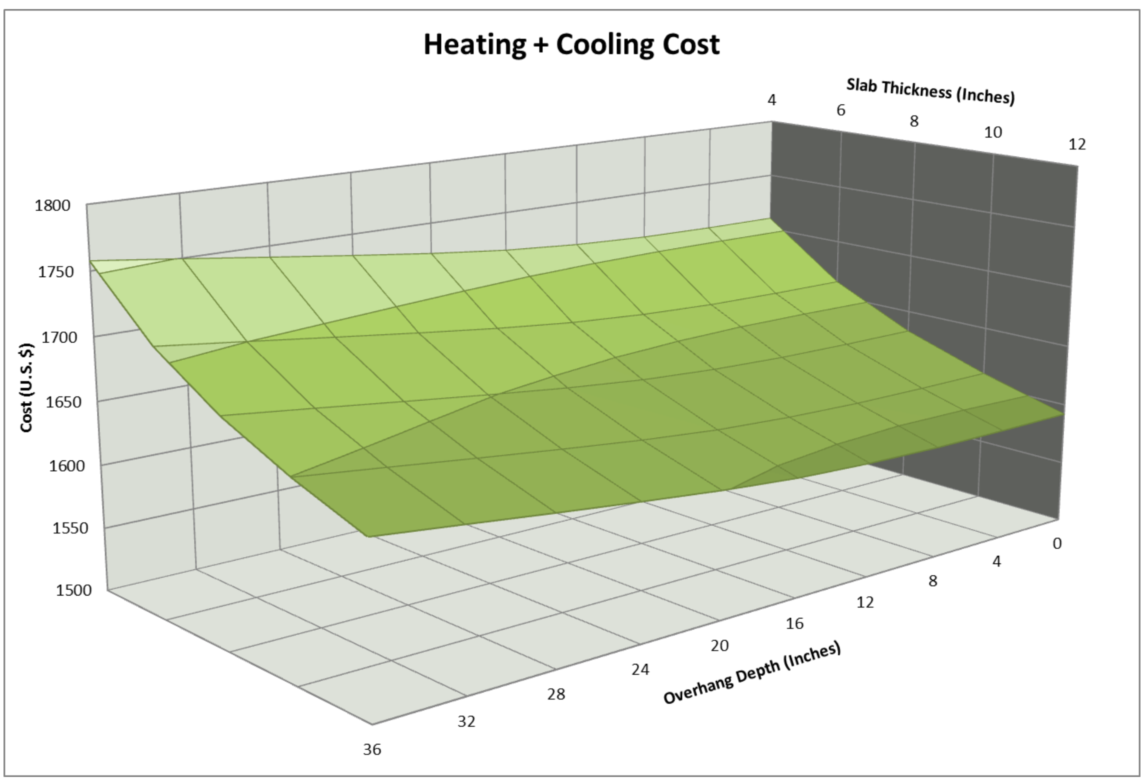
With a WWR of 12.4 the minimum cost of $1,618 occurs with a 12” Slab and a 4” Overhang.

15.1 WWR:





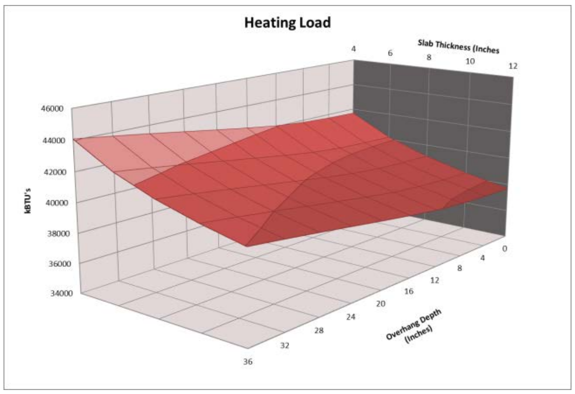
Colonial Energy Star 15.1 WWR Heating Load Colonial Energy Star 15.1 WWR Cooling Load

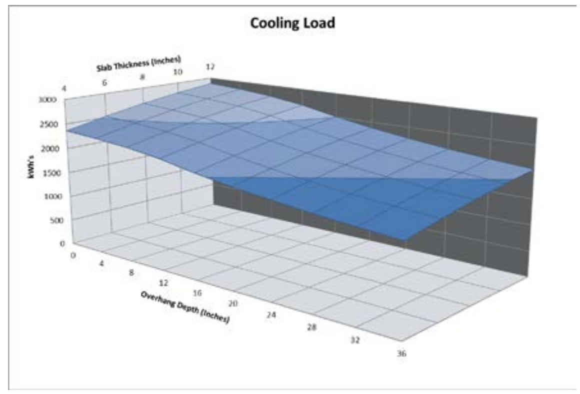


Colonial Energy Star 15.1 WWR Heating and Cooling Cost

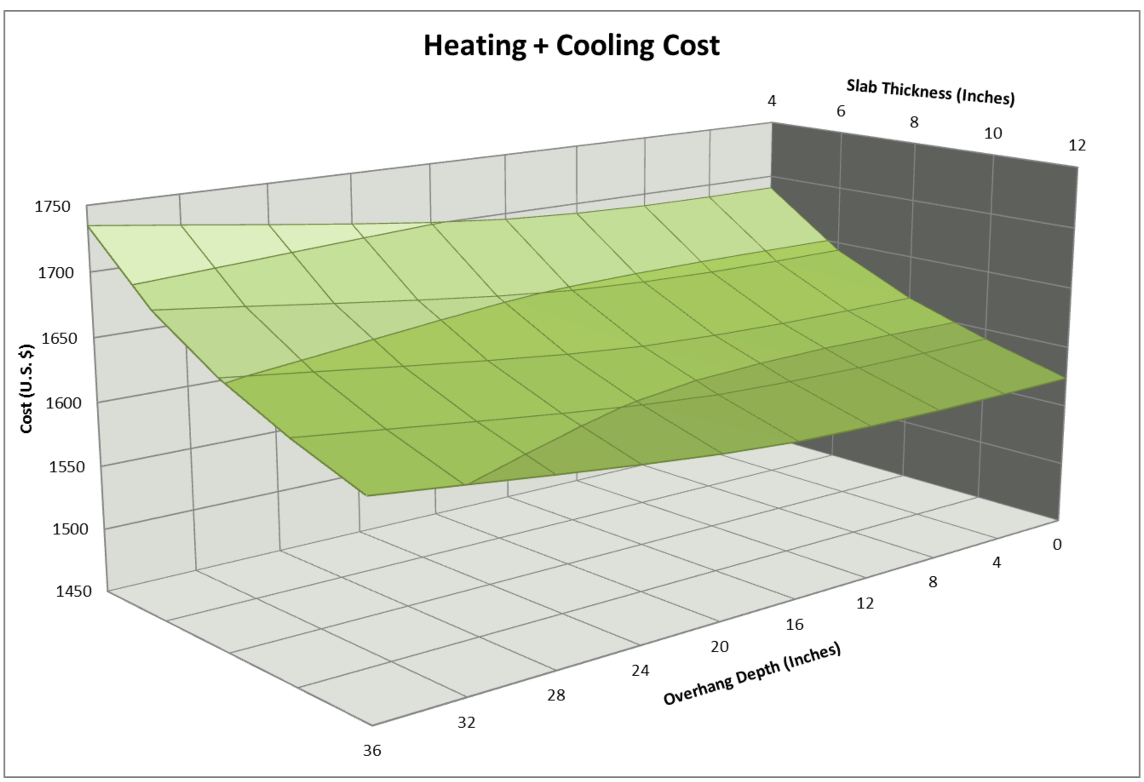
With a WWR of 15.1 the minimum cost of $1,591 occurs with a 12” Slab and an 8” Overhang.

17.8 WWR:





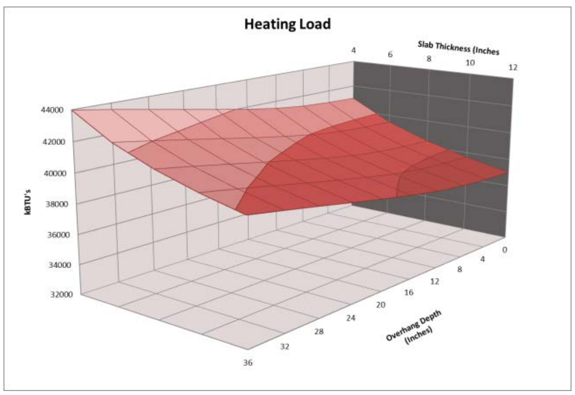
Colonial Energy Star 17.8 WWR Heating Load Colonial Energy Star 17.8 WWR Cooling Load

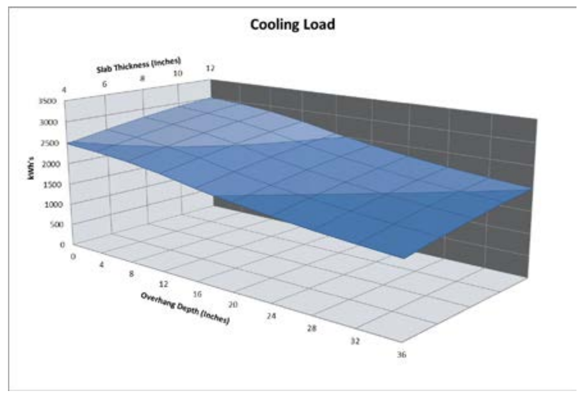


Colonial Energy Star 17.8 WWR Heating and Cooling Cost

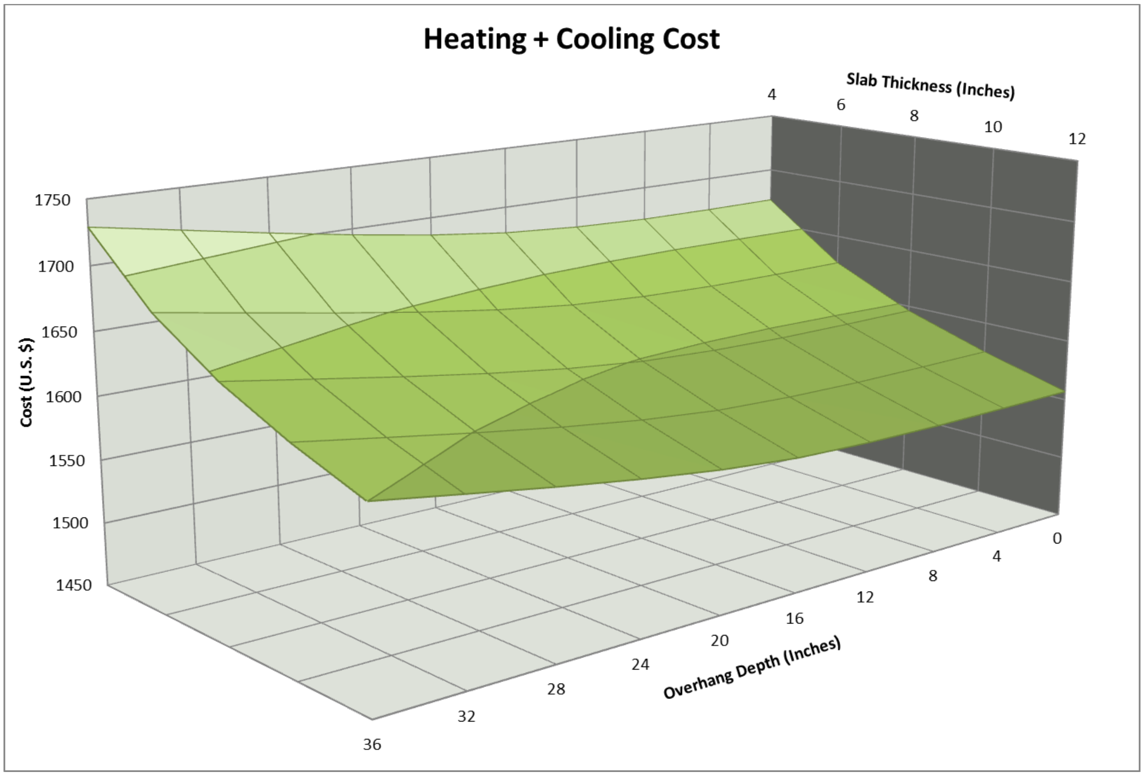
With a WWR of 17.8 the minimum cost of $1,572 occurs with a 12” Slab and an 8” Overhang.

20.6 WWR:





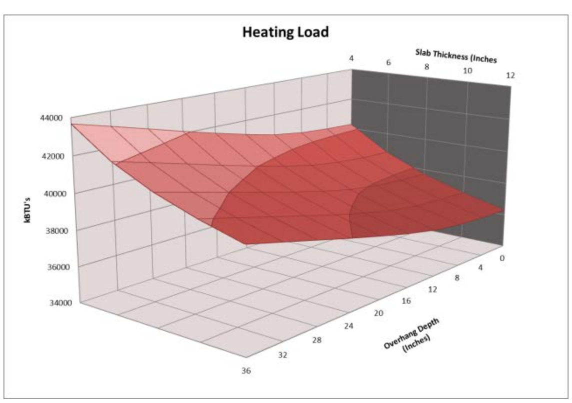
Colonial Energy Star 20.6 WWR Heating Load Colonial Energy Star 20.6 WWR Cooling Load

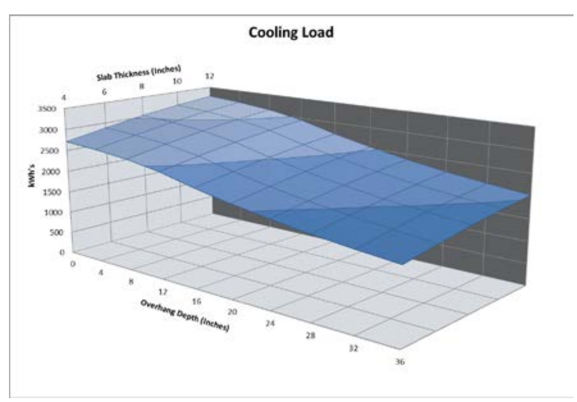


Colonial Energy Star 20.6 WWR Heating and Cooling Cost

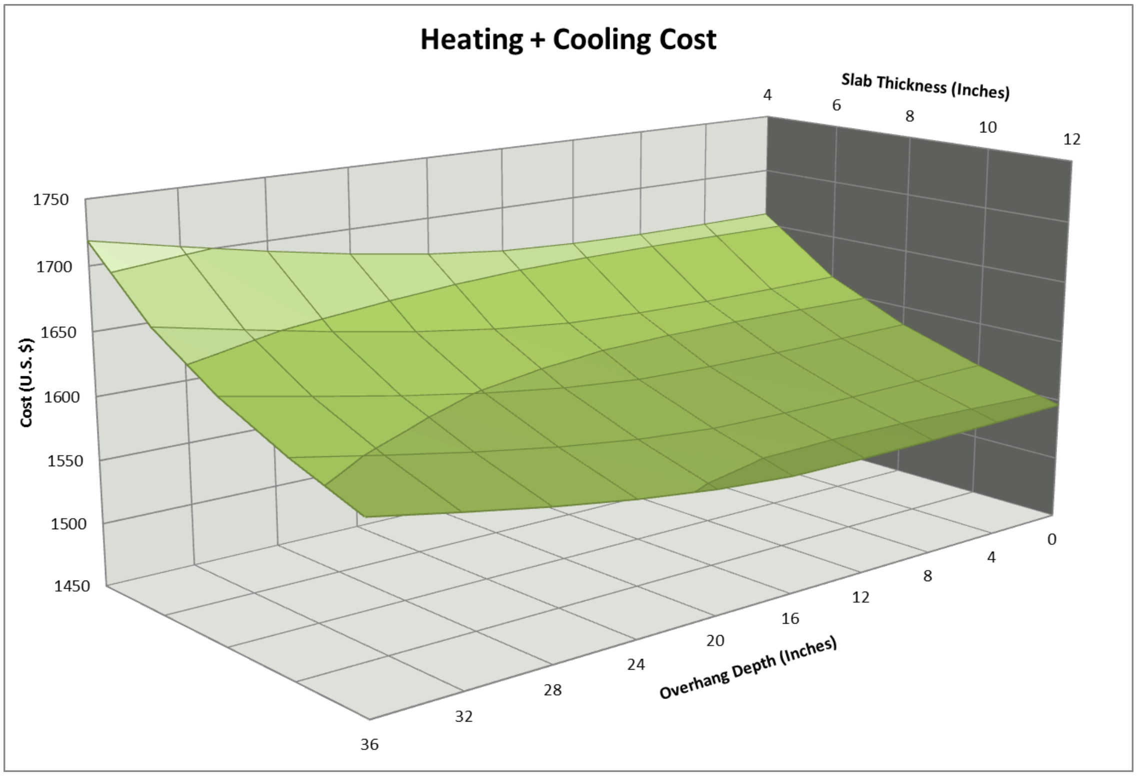
With a WWR of 20.6 the minimum cost of $1,554 occurs with a 12” Slab and an 8” Overhang.

23.3 WWR:





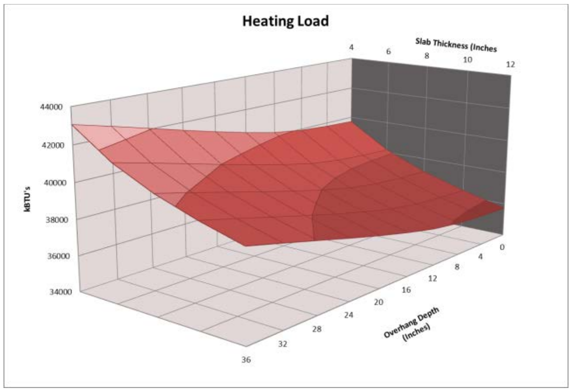
Colonial Energy Star 23.3 WWR Heating Load Colonial Energy Star 23.3 WWR Cooling Load

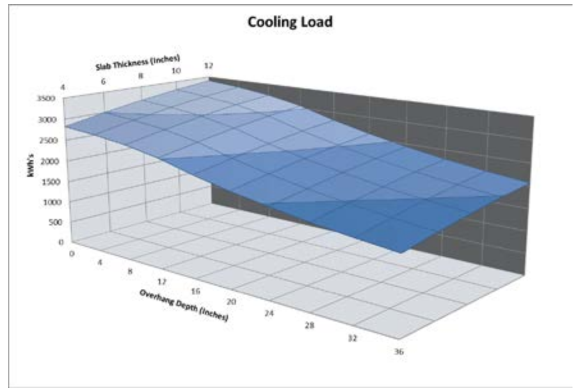


Colonial Energy Star 23.3 WWR Heating and Cooling Cost

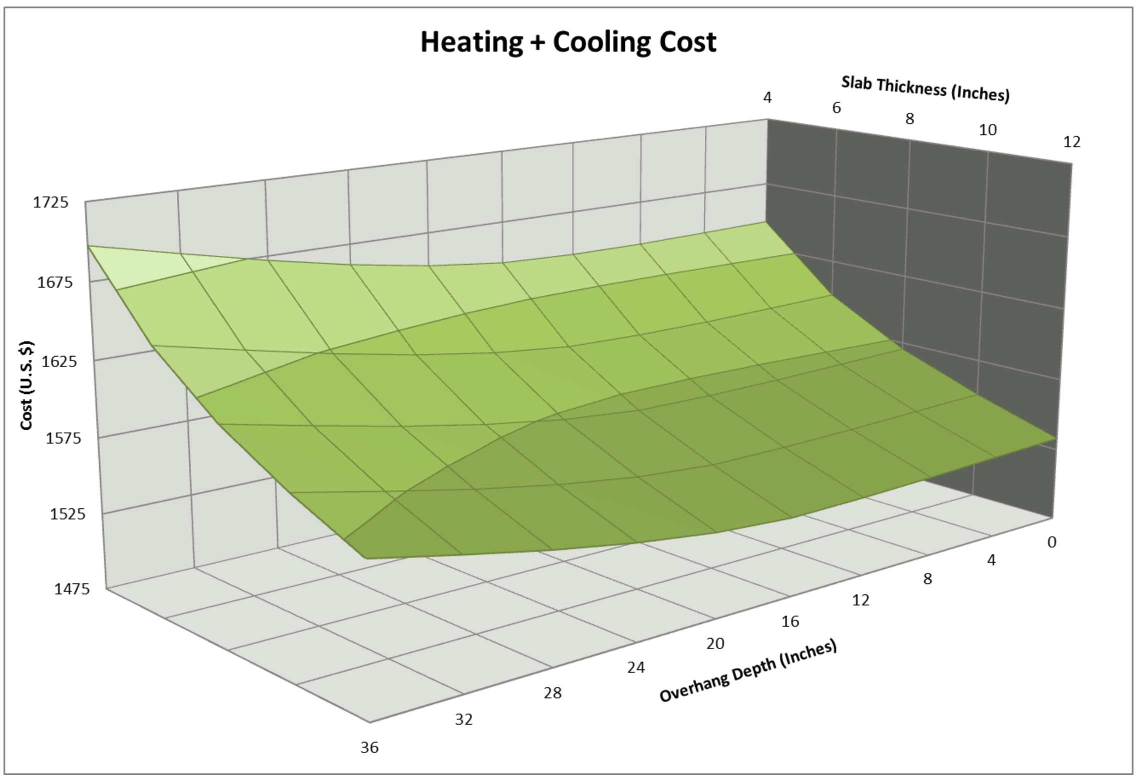
With a WWR of 23.3 the minimum cost of $1,542 occurs with a 12” Slab and a 12” Overhang.

26 WWR:





Colonial Energy Star 26 WWR Heating Load Colonial Energy Star 26 WWR
Cooling Load

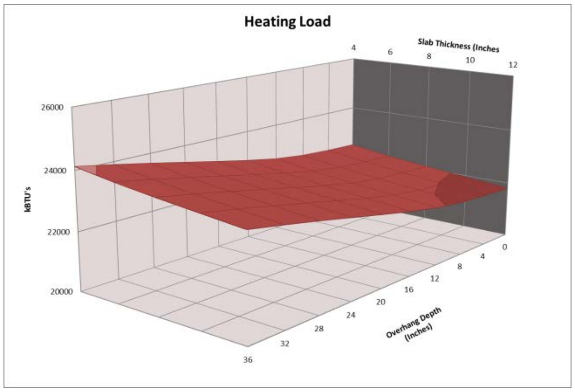


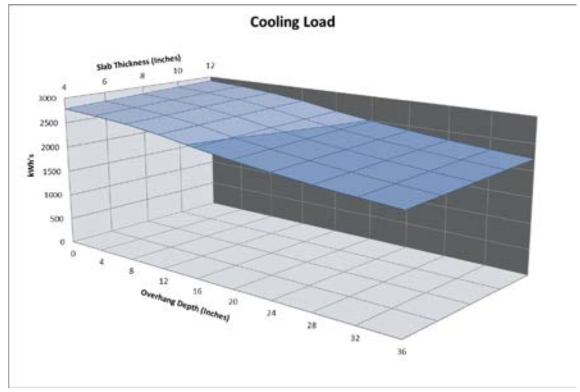
Colonial Energy Star 26 WWR Heating and Cooling Cost

With a WWR of 26 the minimum cost of $1,527 occurs with a 12” Slab and a 16” Overhang.

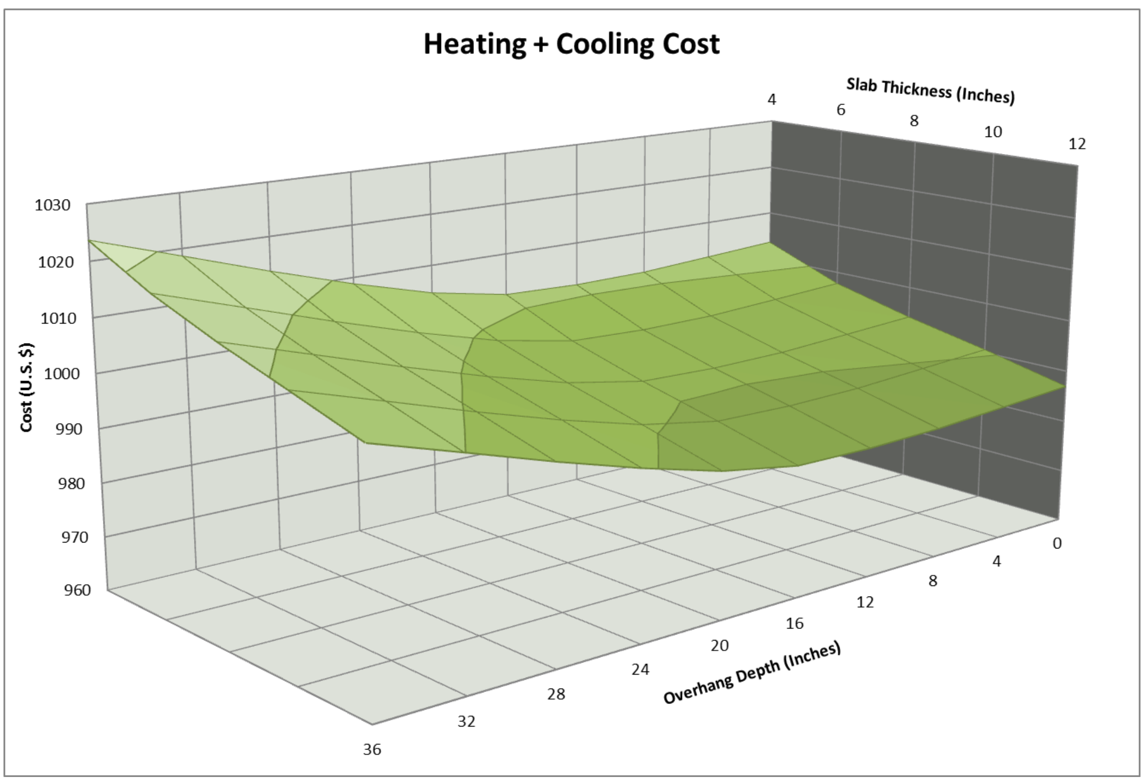
Energy Star- Passive House Avg.

<u>12.4 WWR:</u>





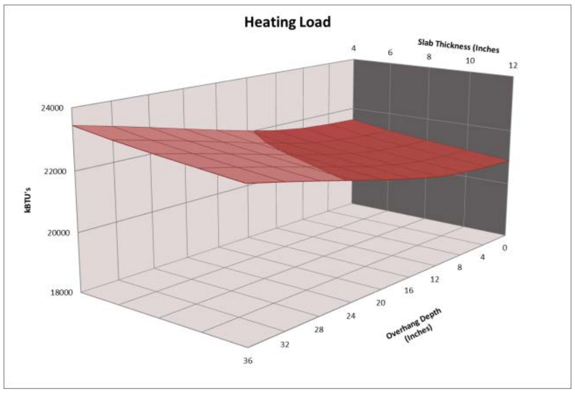
Colonial Energy Star-PH 12.4 WWR Heating Load   Colonial Energy Star-PH 12.4 WWR Cooling Load



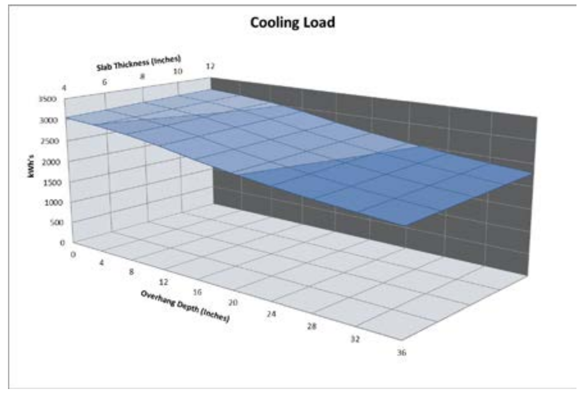
Colonial Energy Star-PH 12.4 WWR Heating and Cooling Cost

With a WWR of 12.4 the minimum cost of $984 occurs with a 12” Slab and a 12” Overhang.

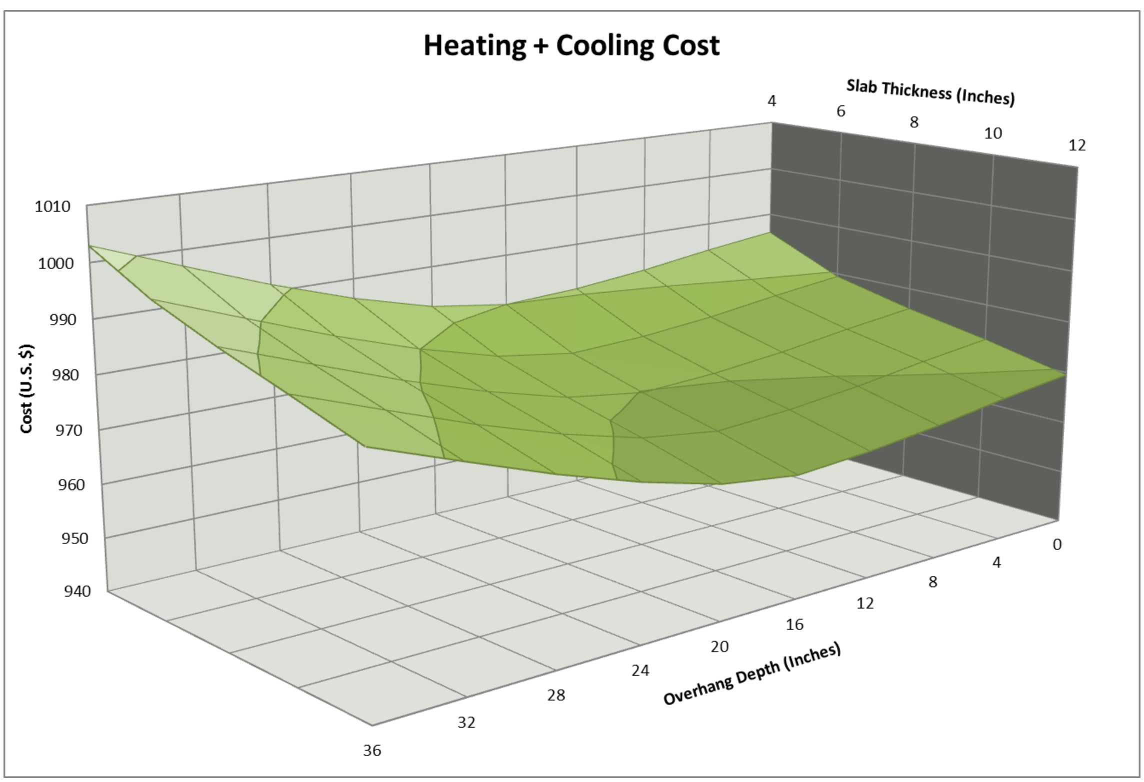
15.1 WWR:



Colonial Energy Star-PH 15.1 WWR Heating Load



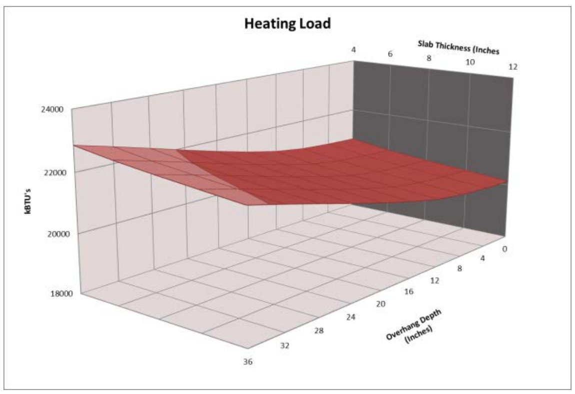
Colonial Energy Star-PH 15.1 WWR Cooling Load

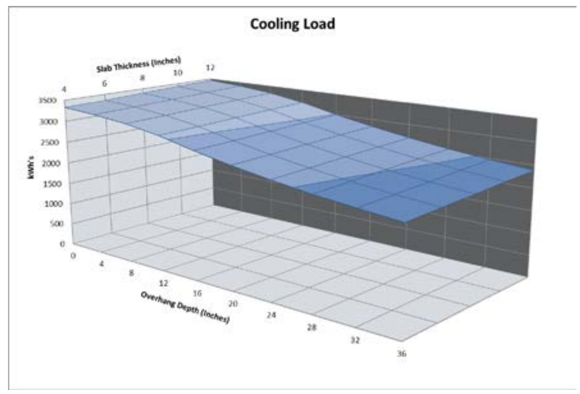


Colonial Energy Star-PH 15.1 WWR Heating and Cooling Cost

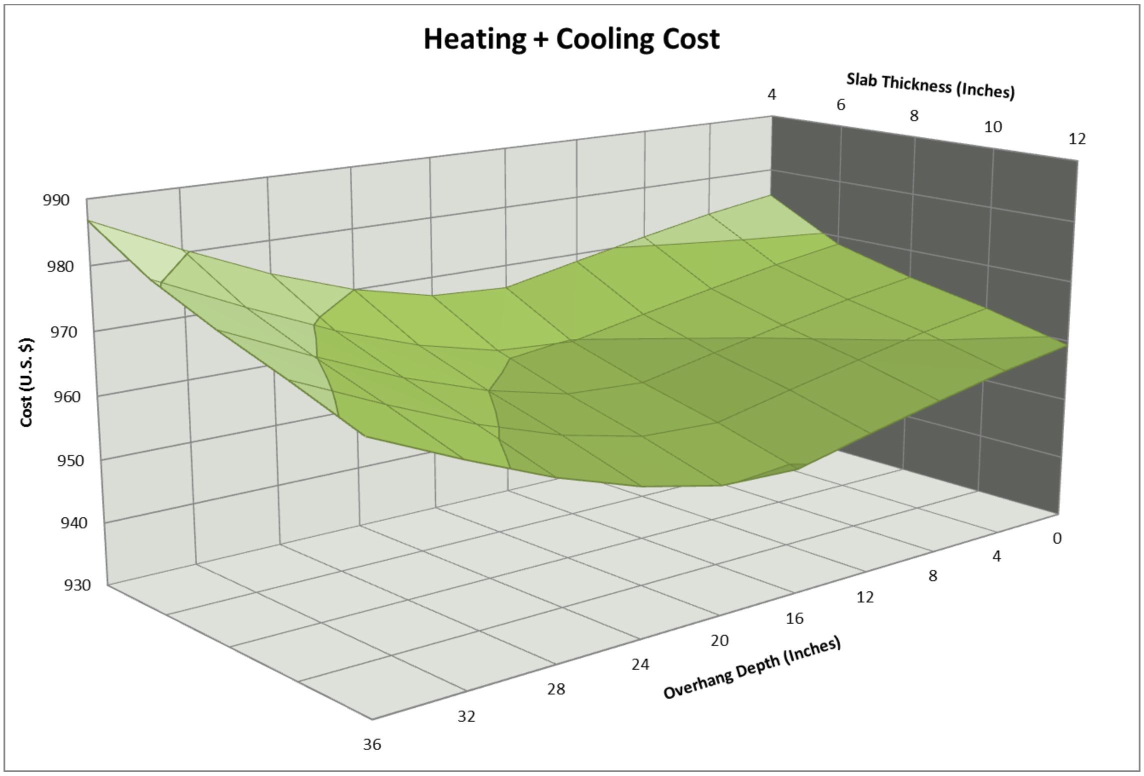
With a WWR of 15.1 the minimum cost of $962 occurs with a 12” Slab and a 16” Overhang.

<u>17.8 WWR:</u>





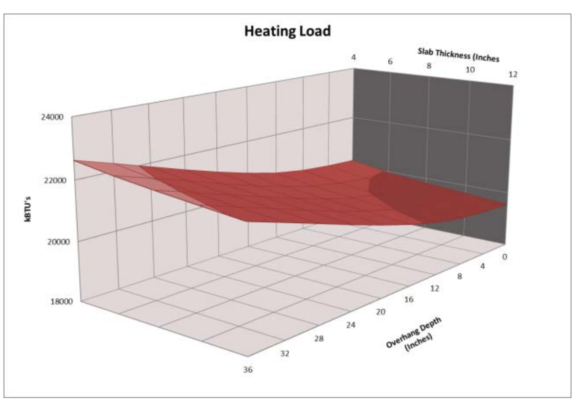
Colonial Energy Star-PH 17.8 WWR Heating Load Colonial Energy Star-PH 17.8 WWR Cooling Load

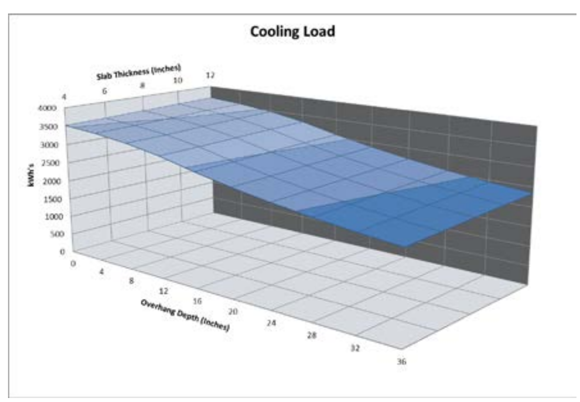


Colonial Energy Star-PH 17.8 WWR Heating and Cooling Cost

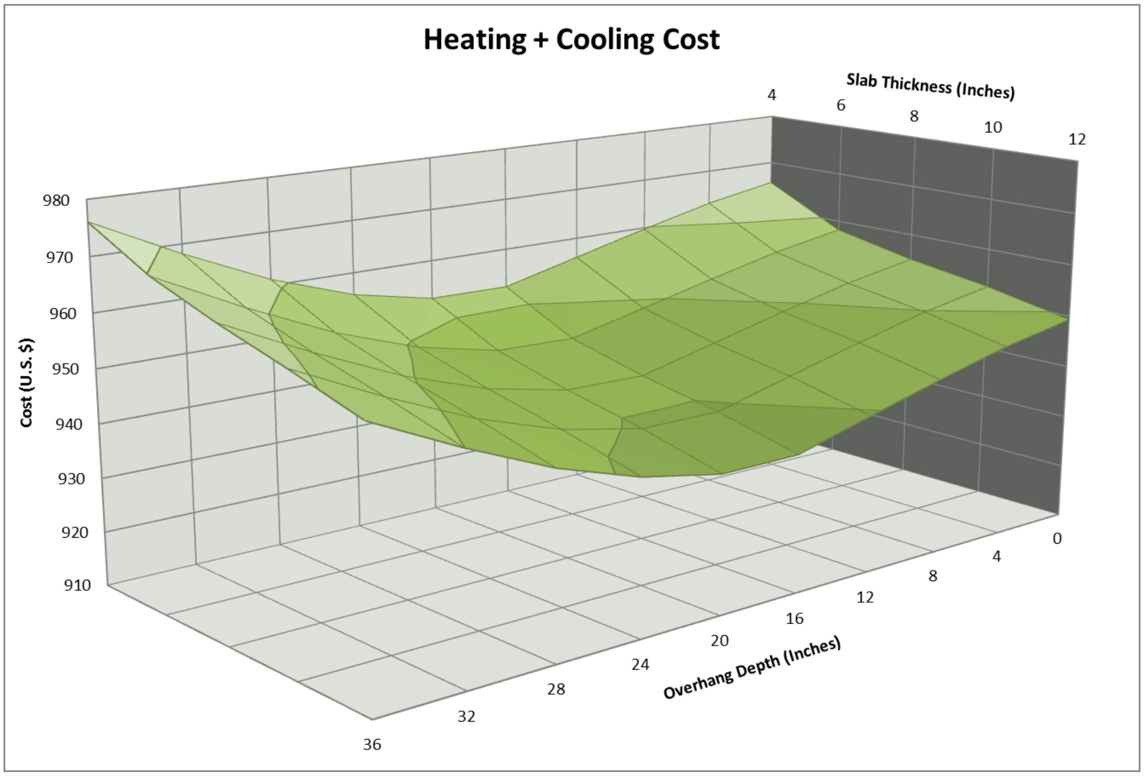
With a WWR of 17.8 the minimum cost of $949 occurs with a 12” Slab and a 16” Overhang.

<u>20.6 WWR:</u>





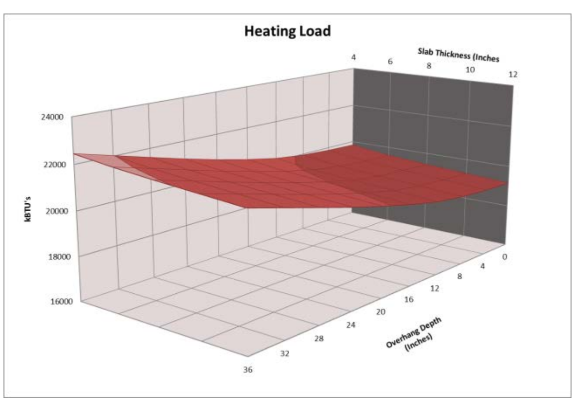
Colonial Energy Star-PH 20.6 WWR Heating Load   Colonial Energy Star-PH 20.6 WWR Cooling Load

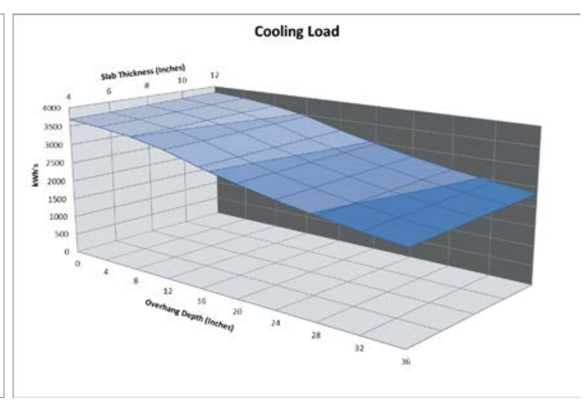


Colonial Energy Star-PH 20.6 WWR Heating and Cooling Cost

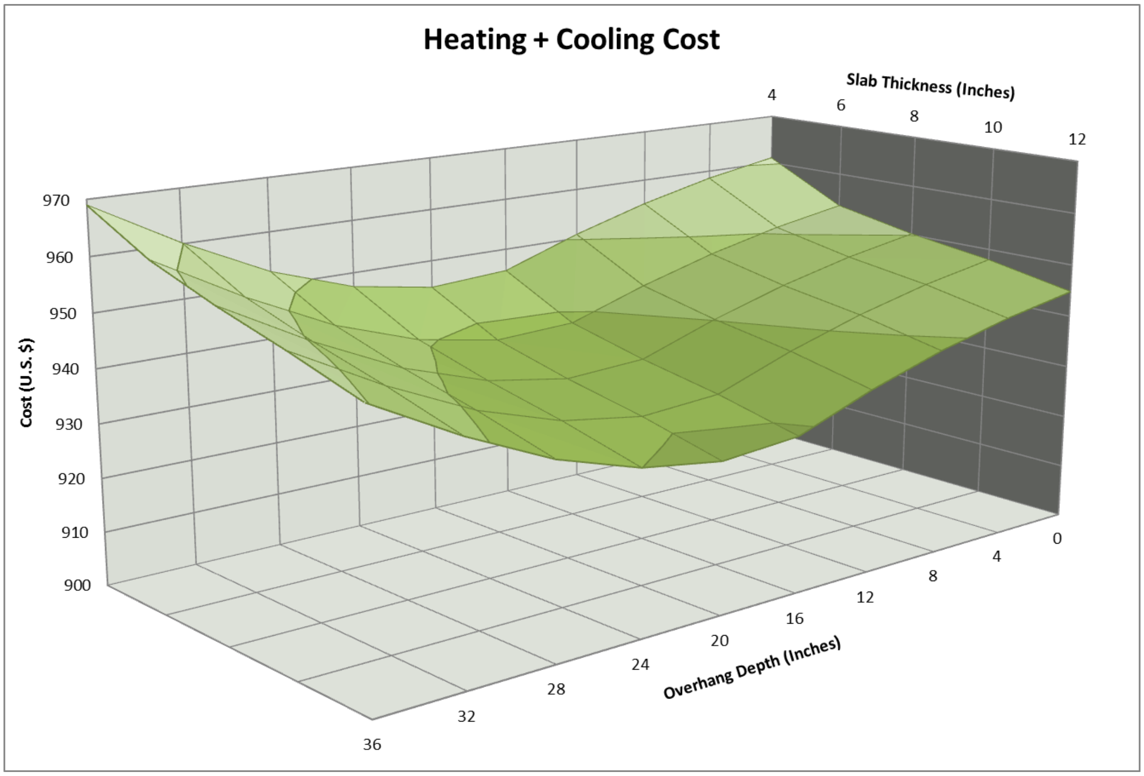
With a WWR of 20.6 the minimum cost of $935 occurs with a 12" Slab and a 20" Overhang.

<u>23.3 WWR:</u>





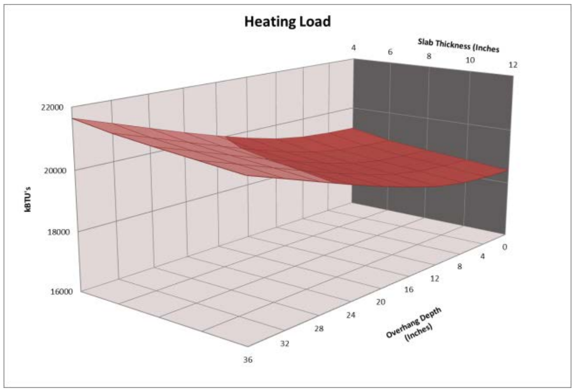
Colonial Energy Star-PH 23.3 WWR Heating Load   Colonial Energy Star-PH 23.3 WWR Cooling Load



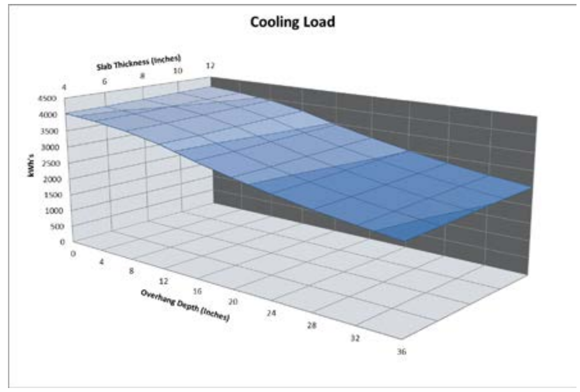
Colonial Energy Star-PH 23.3 WWR Heating and Cooling Cost

With a WWR of 23.3 the minimum cost of $927 occurs with a 12” Slab and a 20” Overhang.

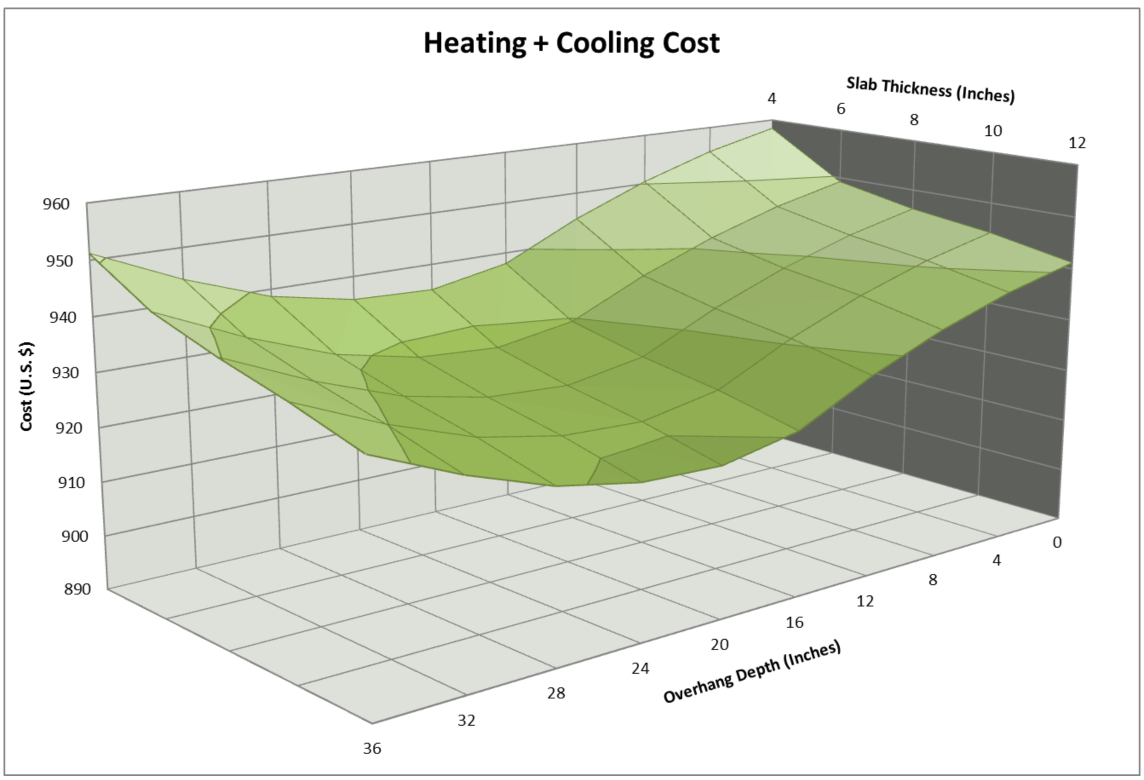
26 WWR:



Colonial Energy Star-PH 26 WWR Heating Load



Colonial Energy Star-PH 26 WWR Cooling Load

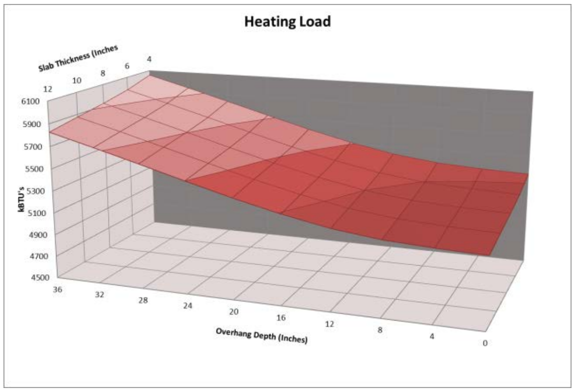


Colonial Energy Star-PH 26 WWR Heating and Cooling Cost

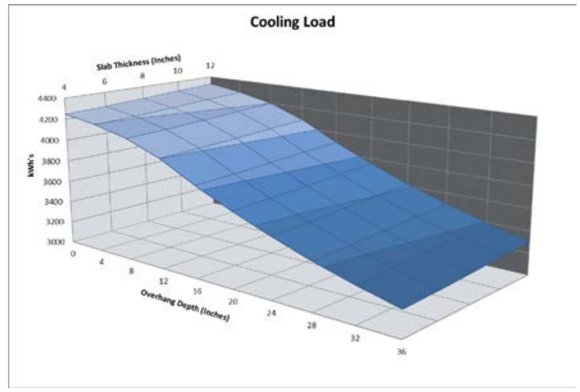
With a WWR of 26 the minimum cost of $917 occurs with a 12" Slab and a 20" Overhang.

Passive House

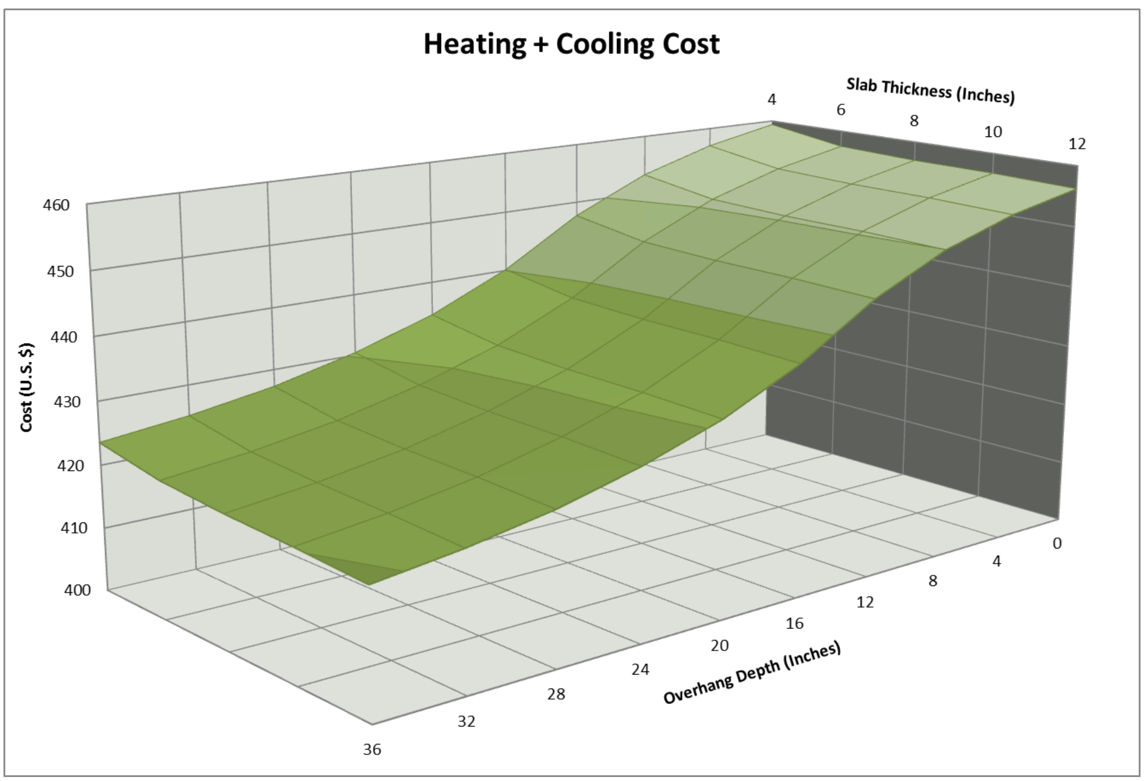
<u>12.4 WWR:</u>



Colonial Passive House 12.4 WWR Heating Load



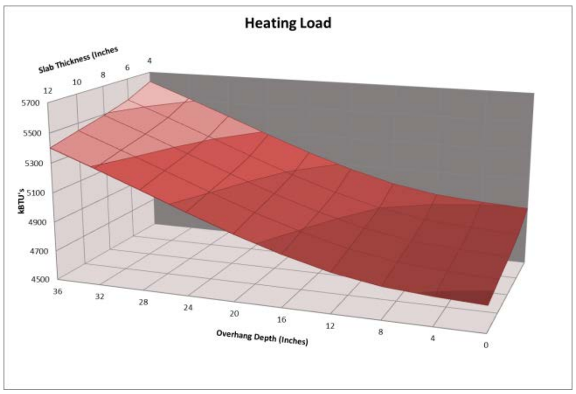
Colonial Passive House 12.4 WWR Cooling Load

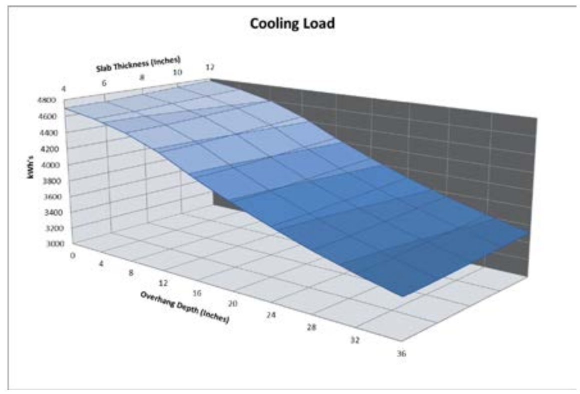


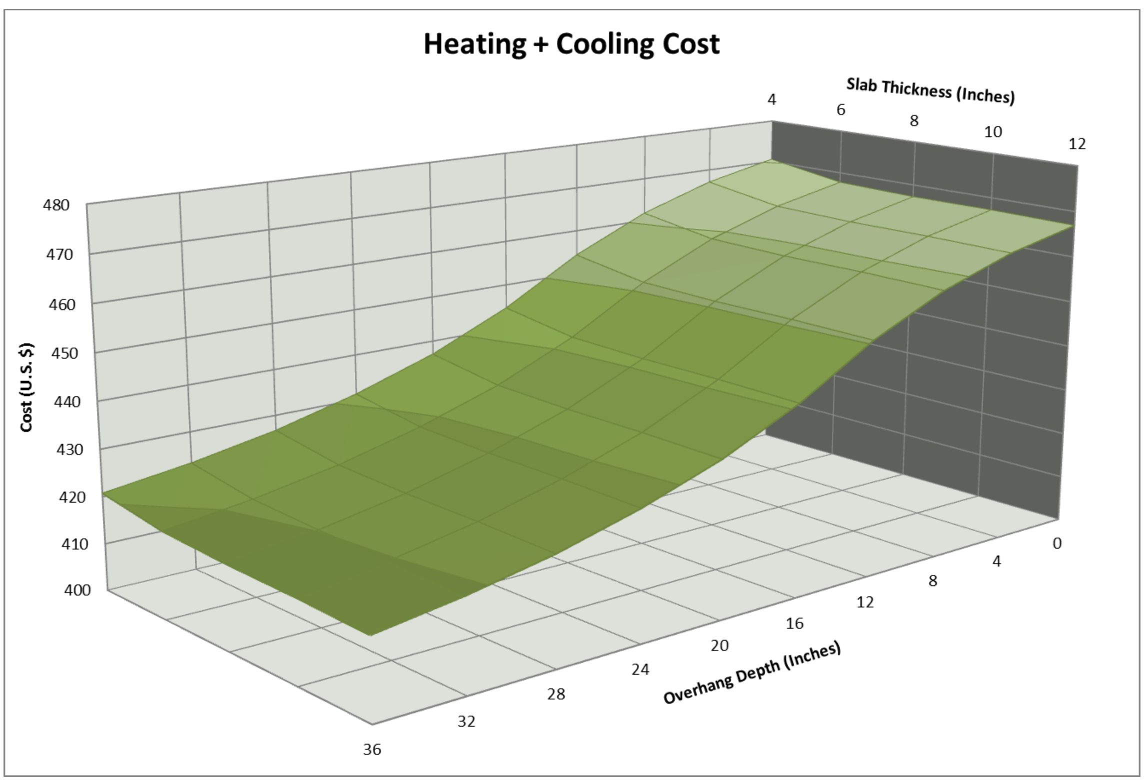
Colonial Passive House 12.4 WWR Heating and Cooling Cost

With a WWR of 12.4 the minimum cost of $419 occurs with a 12" Slab and a 36" Overhang.

15.1 WWR:

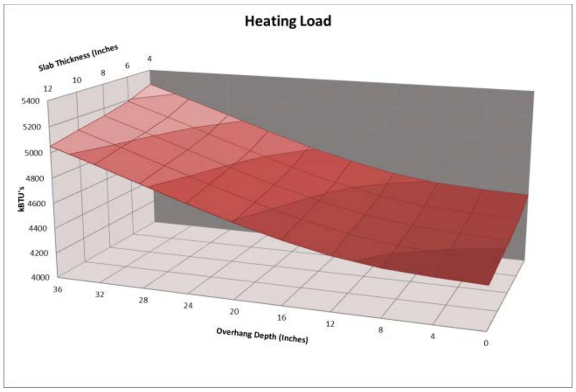




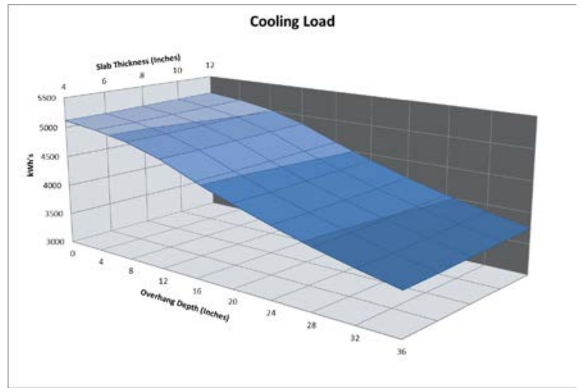


With a WWR of 15.1 the minimum cost of $416 occurs with a 12" Slab and a 36" Overhang.

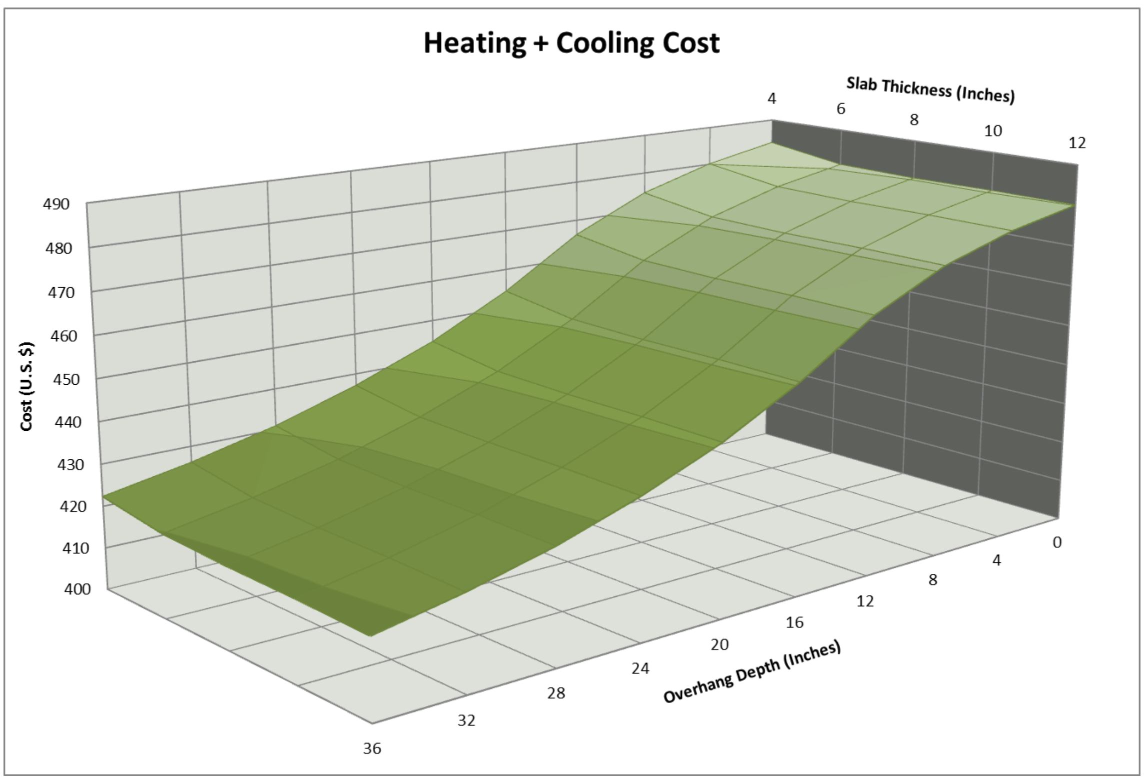
17.8 WWR:



Heating Load
Slab Thickness (Inches
12 10 8 6 4
5400 5200 5000 4800 4600 4400 4200 4000
kBTU's
36 32 28 24 20 16 12 8 4 0
Overhang Depth (Inches)



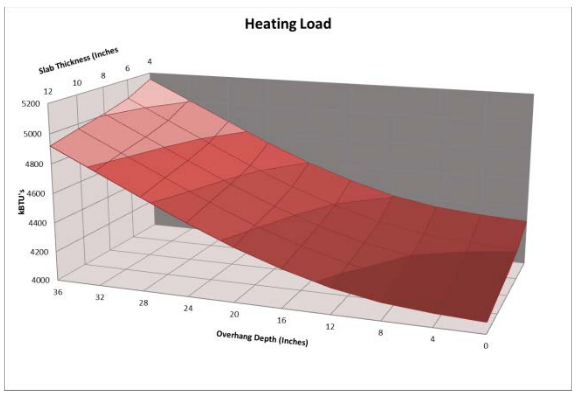
Cooling Load
Slab Thickness (Inches)
4 6 8 10 12
5500 5000 4500 4000 3500 3000
kWh's
0 4 8 12 16 20 24 28 32 36
Overhang Depth (Inches)

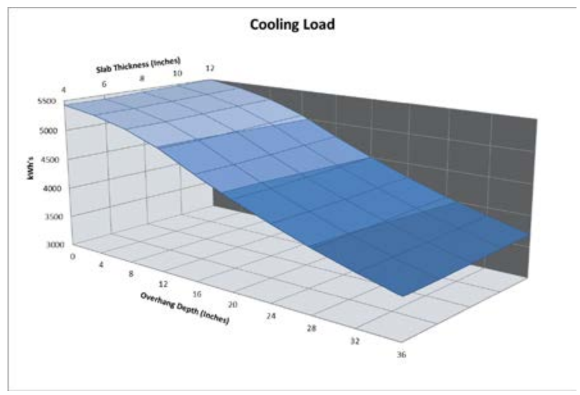


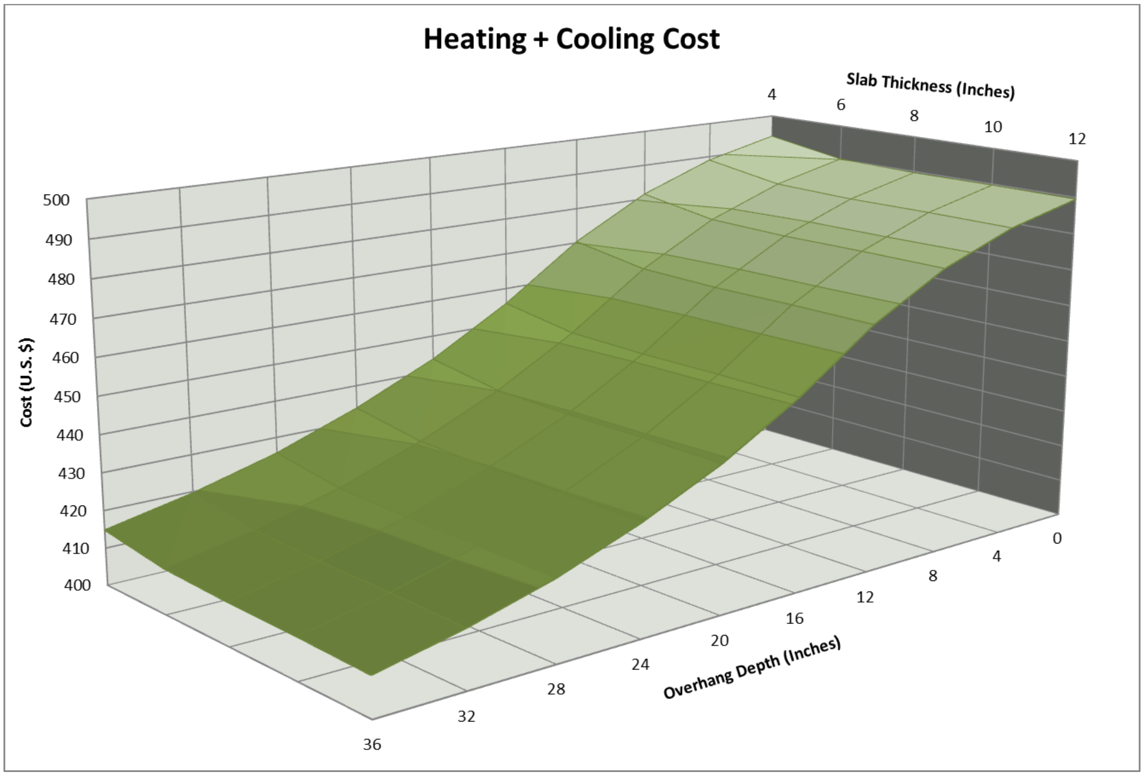
Heating + Cooling Cost
Slab Thickness (Inches)
4 6 8 10 12
490 480 470 460 450 440 430 420 410 400
Cost (U.S. $)
36 32 28 24 20 16 12 8 4 0
Overhang Depth (Inches)

With a WWR of 17.8 the minimum cost of $418 occurs with a 12” Slab and a 36” Overhang.

20.6 WWR:

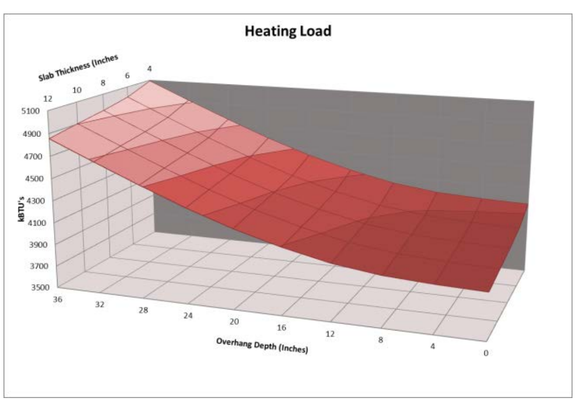


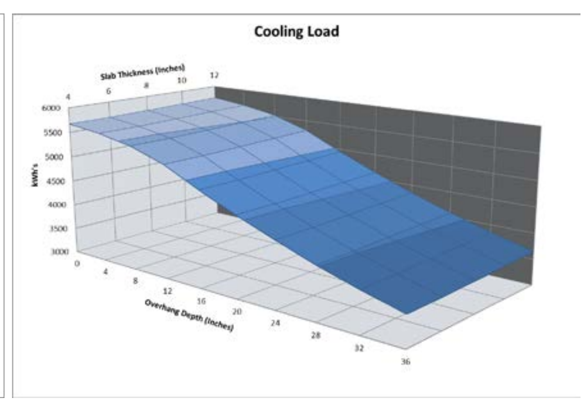


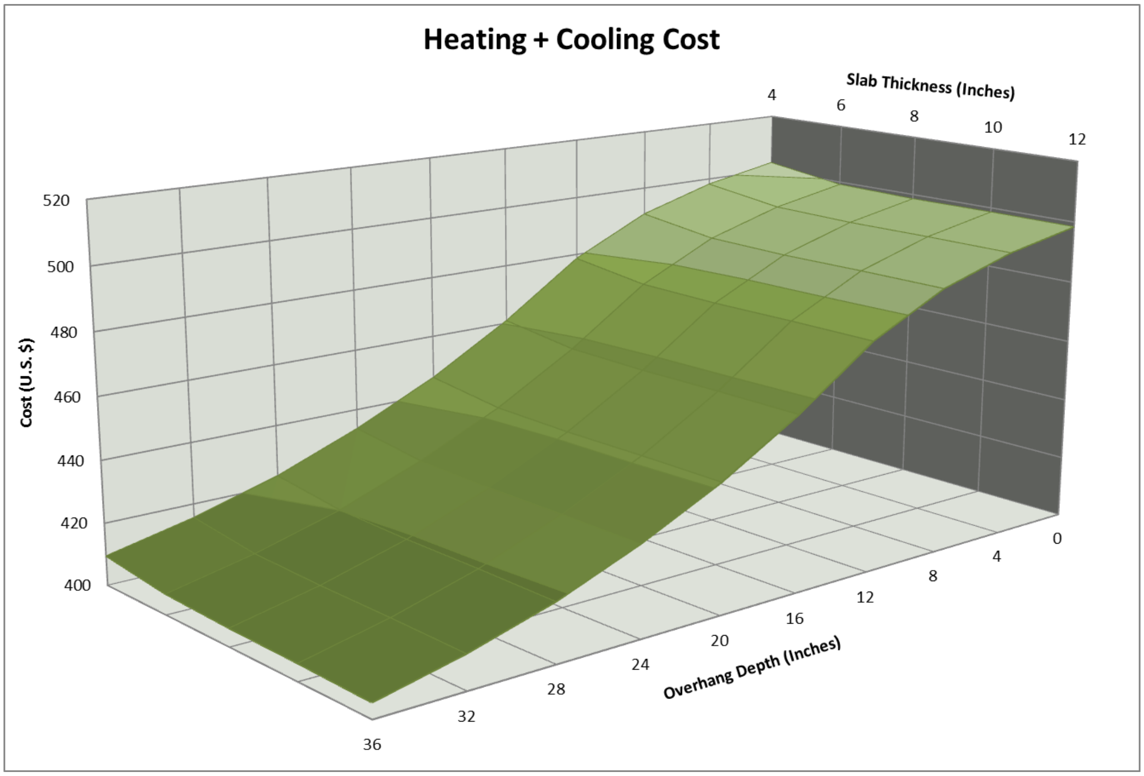


With a WWR of 20.6 the minimum cost of $410 occurs with a 12” Slab and a 36” Overhang.

23.3 WWR:

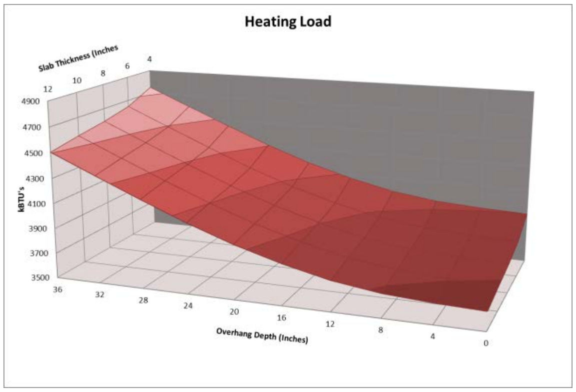


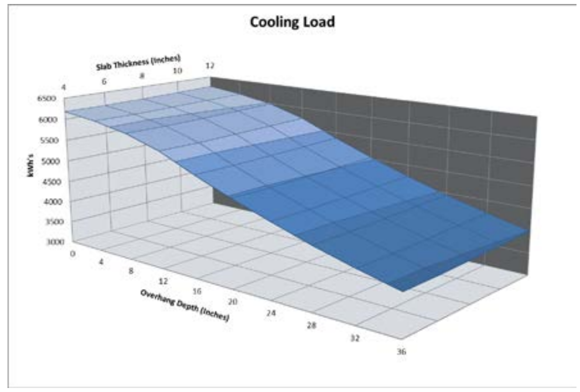


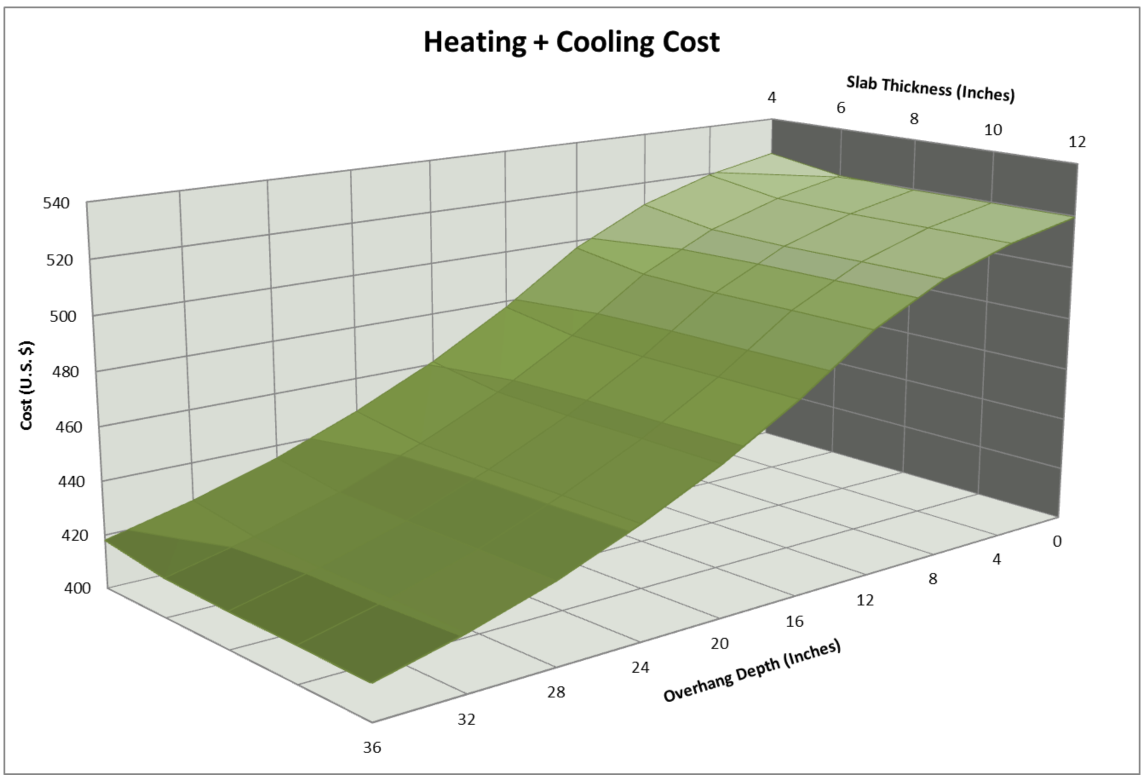


With a WWR of 23.3 the minimum cost of $404 occurs with a 12” Slab and a 36” Overhang.

26 WWR:





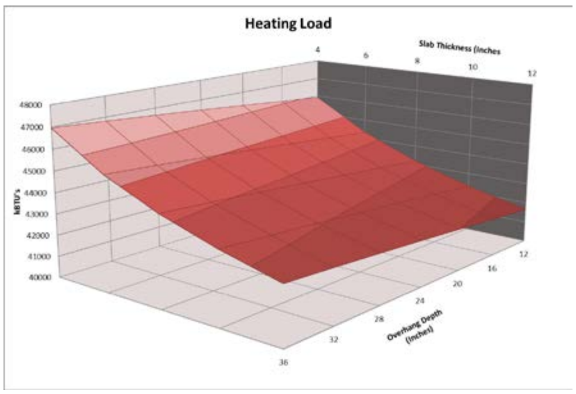


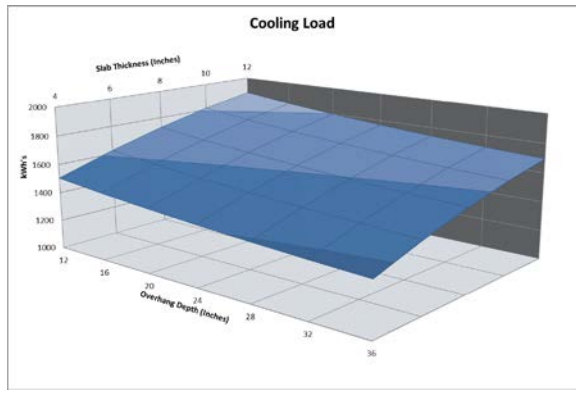
With a WWR of 26 the minimum cost of $412 occurs with a 12” Slab and a 36” Overhang.

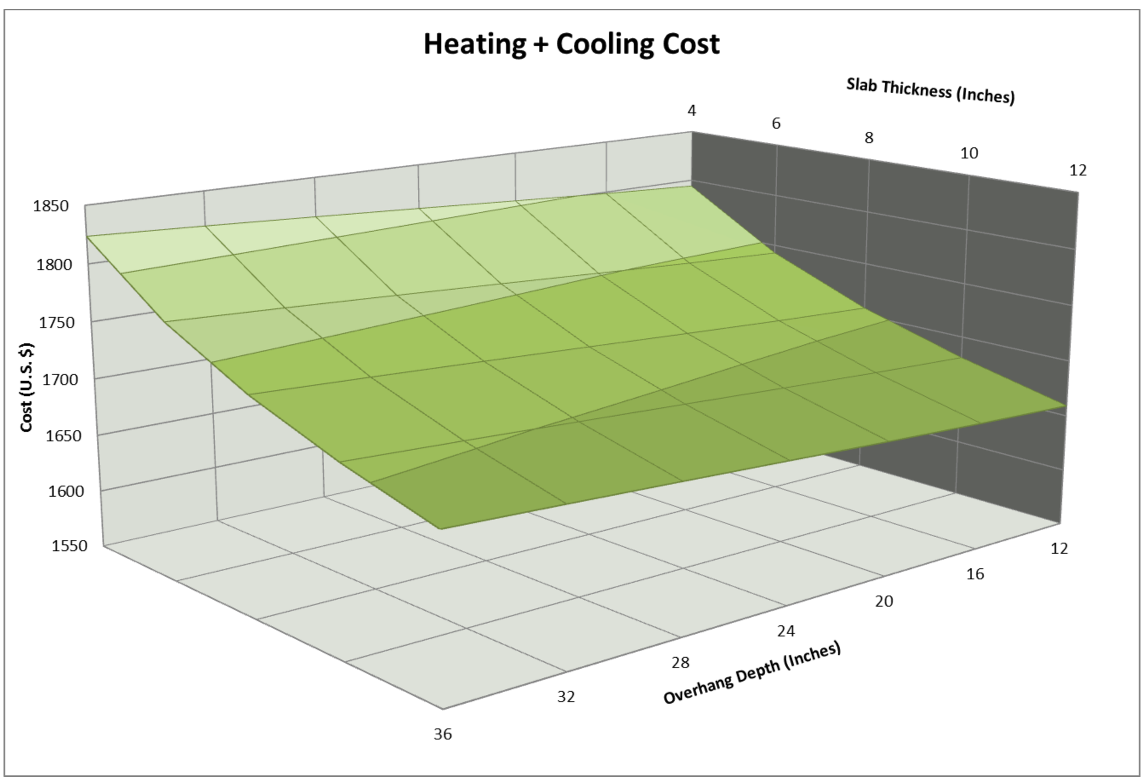
Cape

IECC

12.6 WWR:

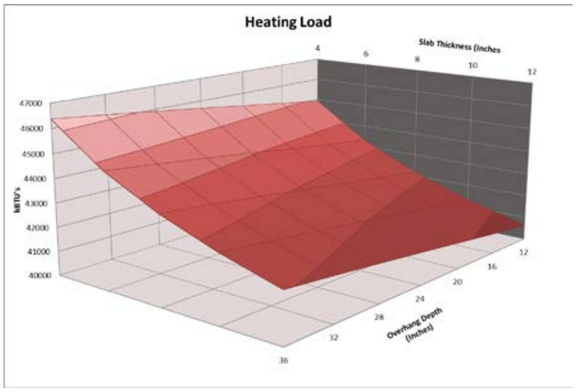


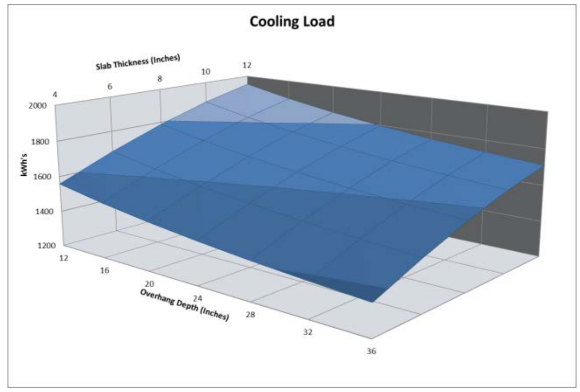


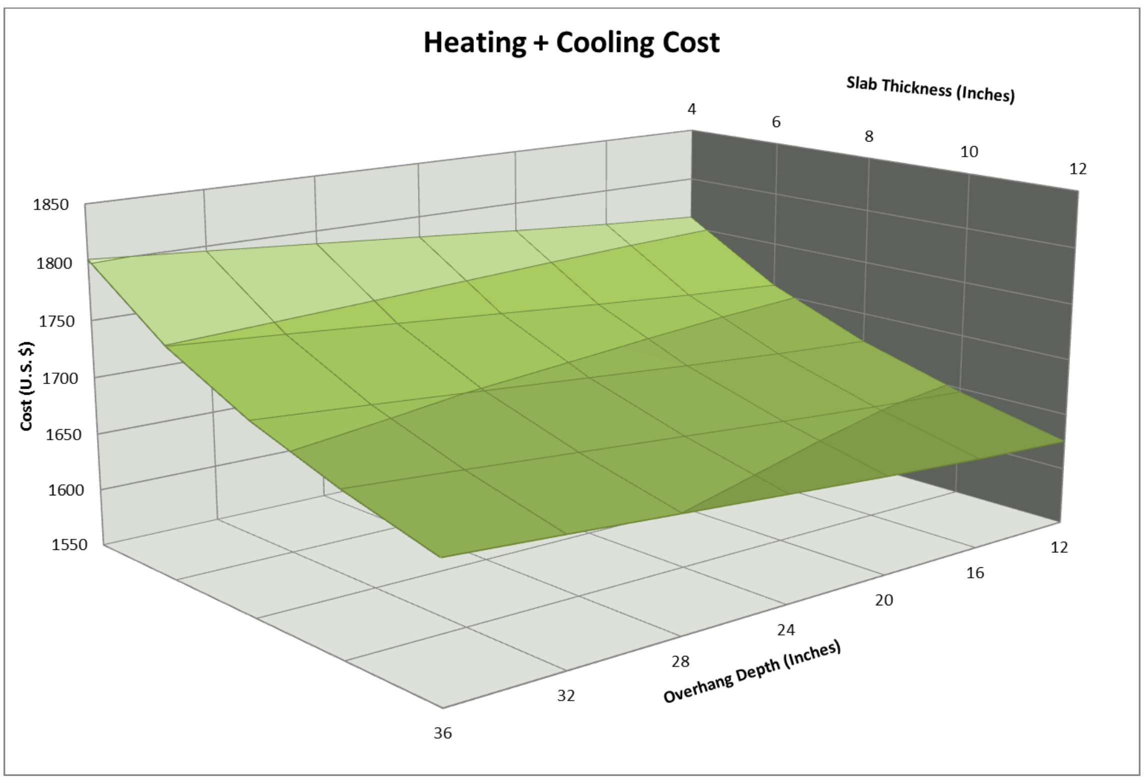


With a WWR of 12.6 the minimum cost of $1,659 occurs with a 12" Slab and a 12" Overhang.

<u>18.9 WWR:</u>

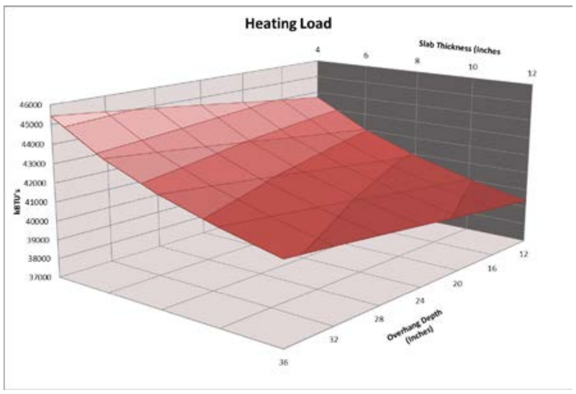


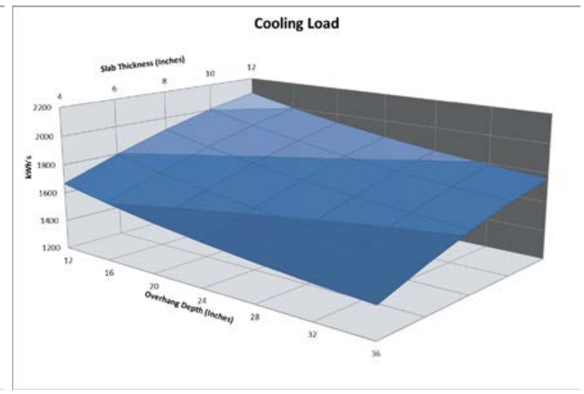


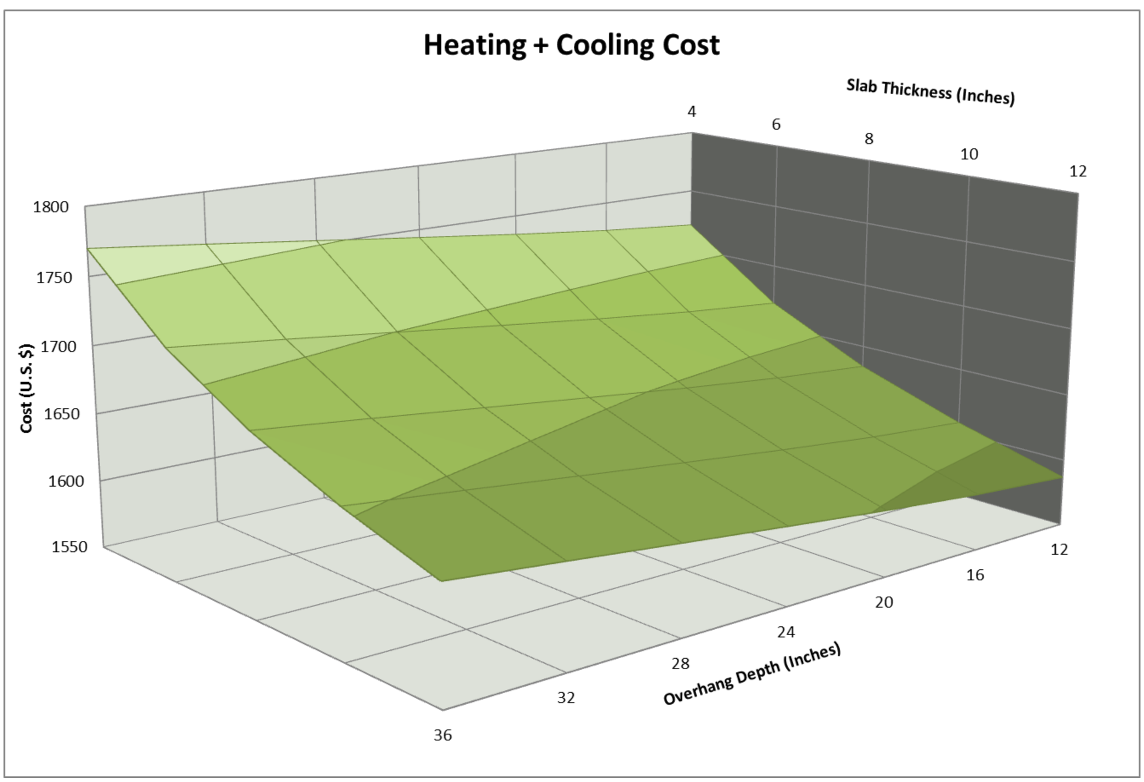


With a WWR of 18.9 the minimum cost of $1,625 occurs with a 12” Slab and a 12” Overhang.

25.2 WWR:

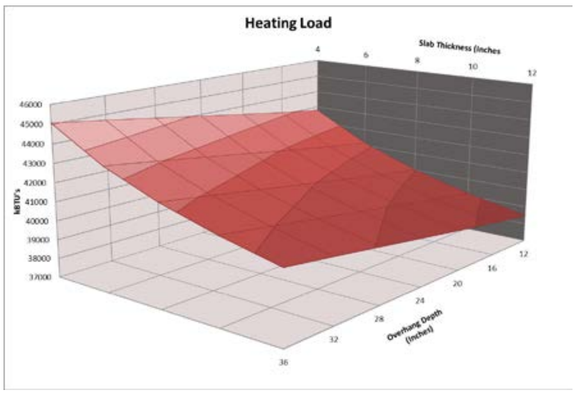


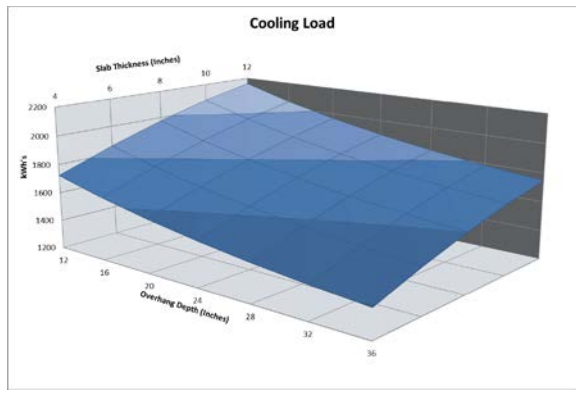


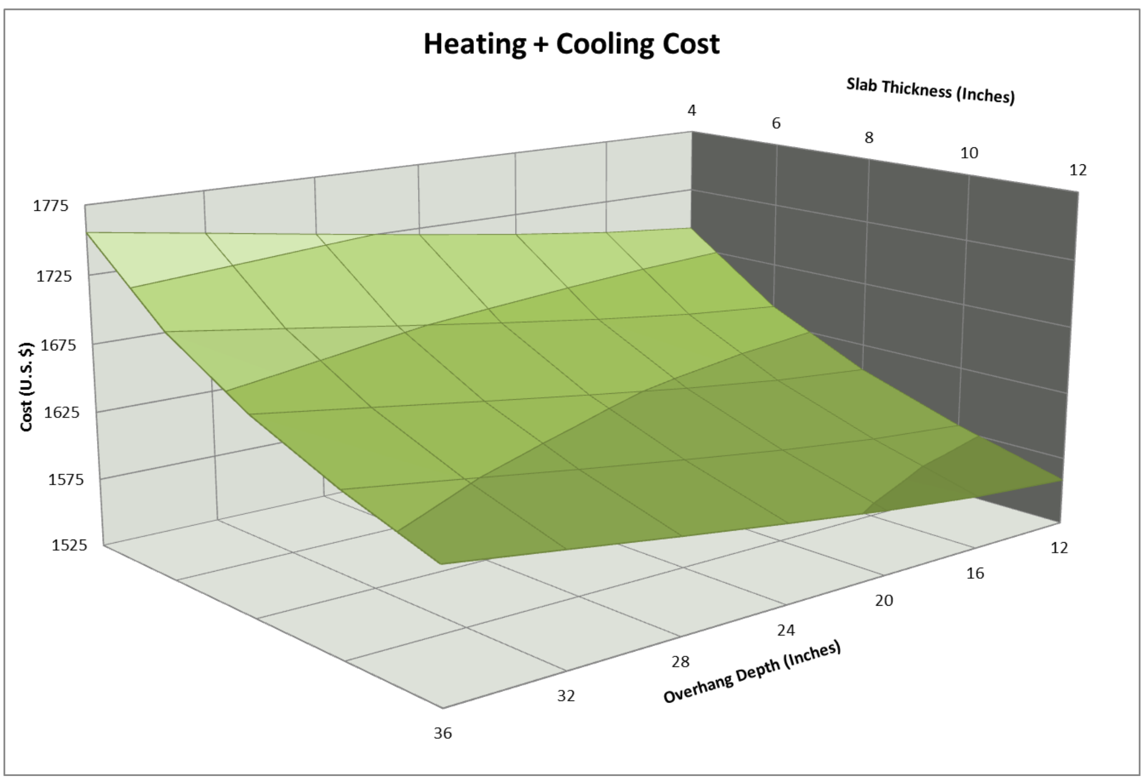


With a WWR of 25.2 the minimum cost of $1,586 occurs with a 12” Slab and a 12” Overhang.

31.5 WWR:


Heating Load
Slab Thickness (Inches
4
6
8
10
12
46000
45000
44000
43000
42000
41000
40000
39000
38000
37000
kBTU's
12
16
20
24
28
32
36
Overhang Depth (Inches)

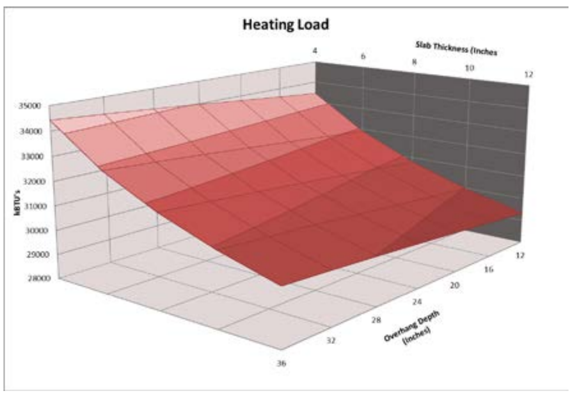

Cooling Load
Slab Thickness (Inches)
4
6
8
10
12
2200
2000
1800
1600
1400
1200
kWh's
12
16
20
24
28
32
36
Overhang Depth (Inches)

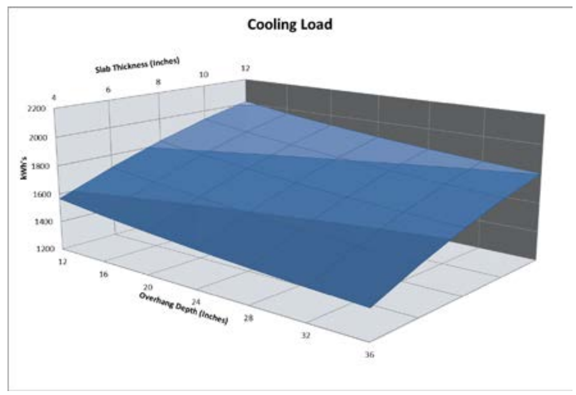

Heating + Cooling Cost
Slab Thickness (Inches)
4
6
8
10
12
1775
1725
1675
1625
1575
1525
Cost (U.S. $)
12
16
20
24
28
32
36
Overhang Depth (Inches)

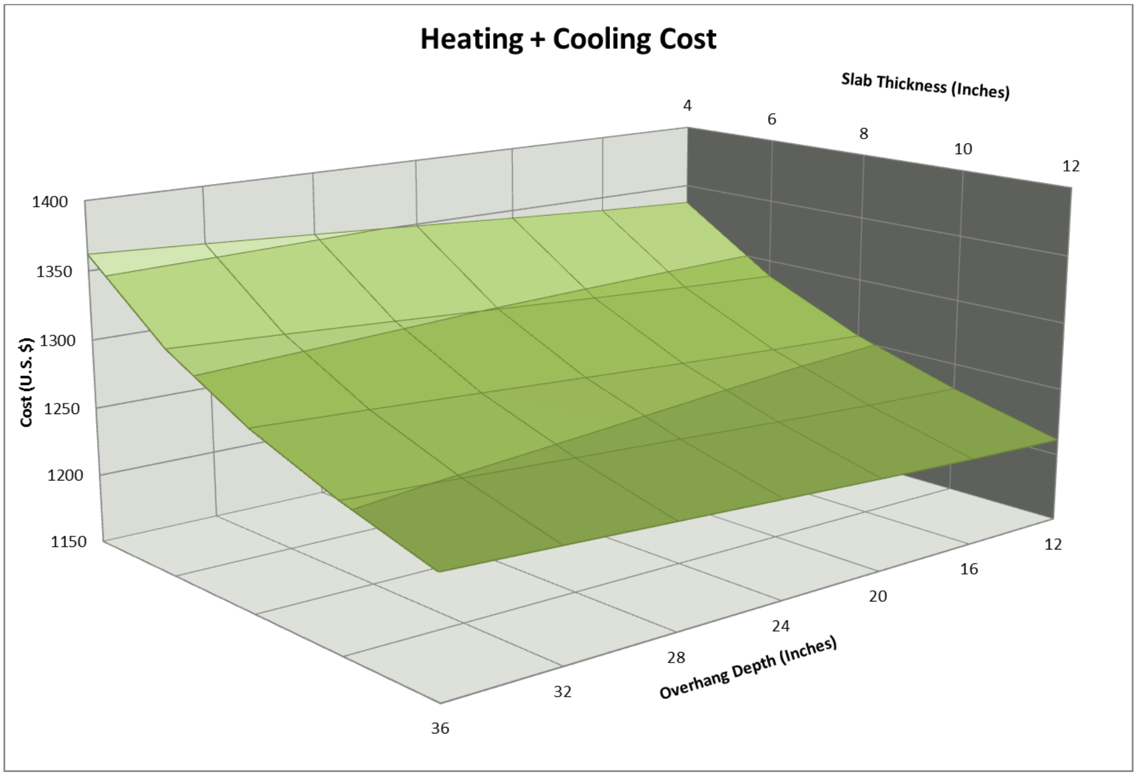
With a WWR of 31.5 the minimum cost of $1,558 occurs with a 12” Slab and a 12” Overhang.

Energy Star:

<u>**12.6 WWR:**</u>

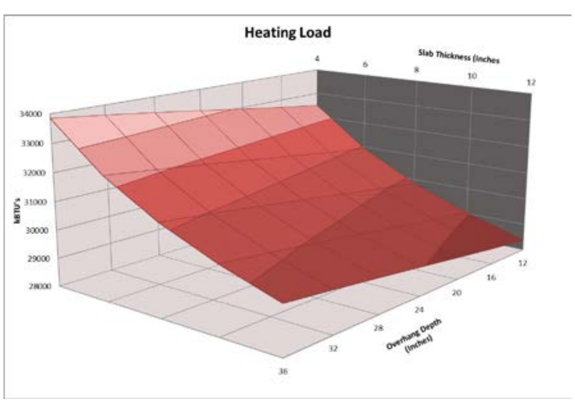


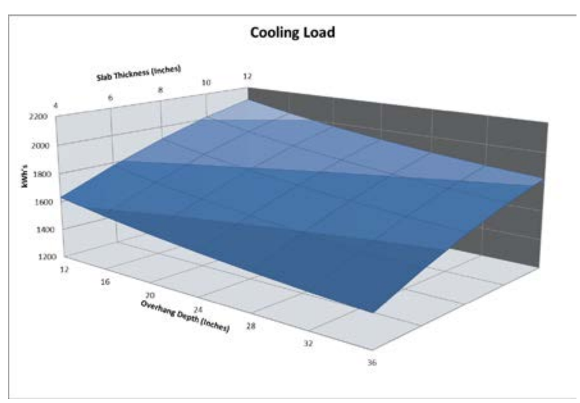


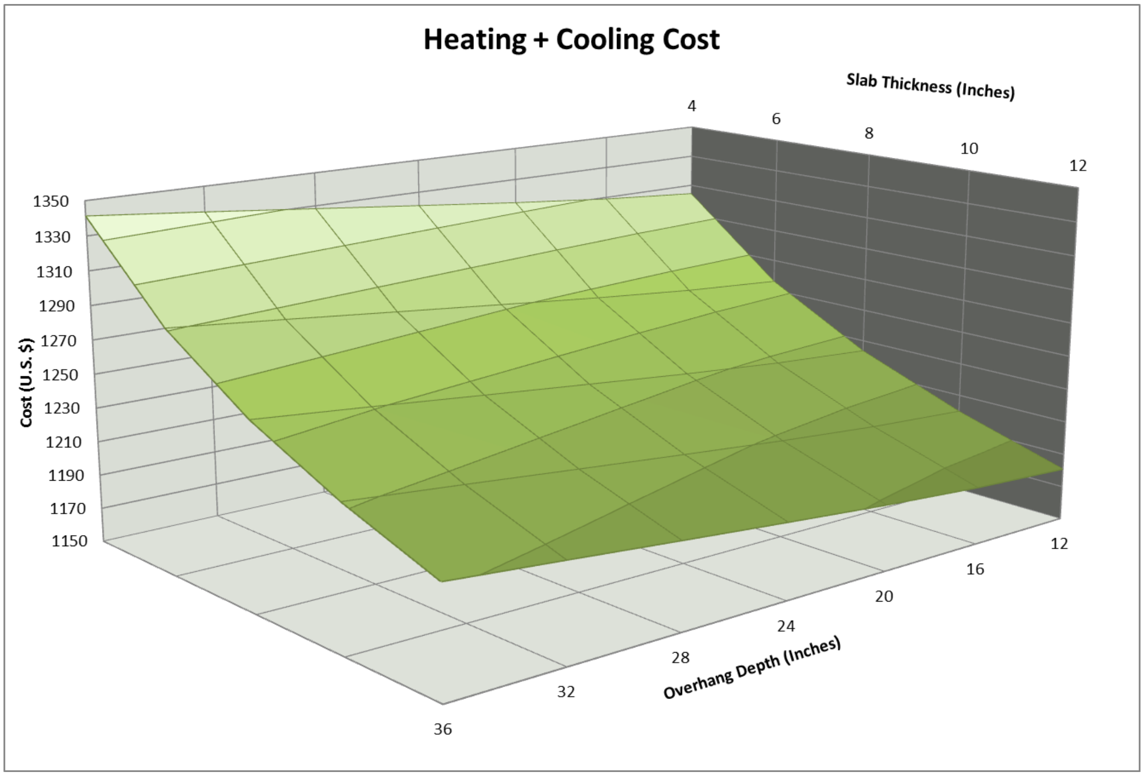


With a WWR of 12.6 the minimum cost of $1,211 occurs with a 12" Slab and a 12" Overhang.

18.9 WWR:

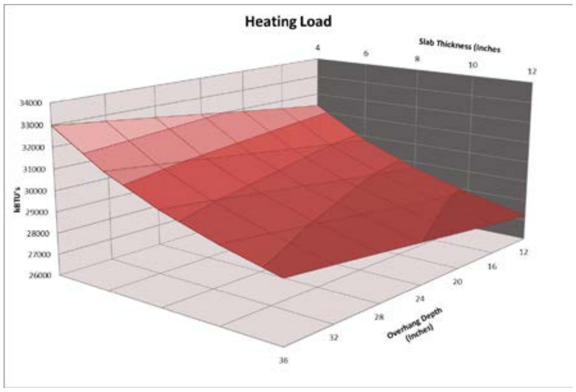


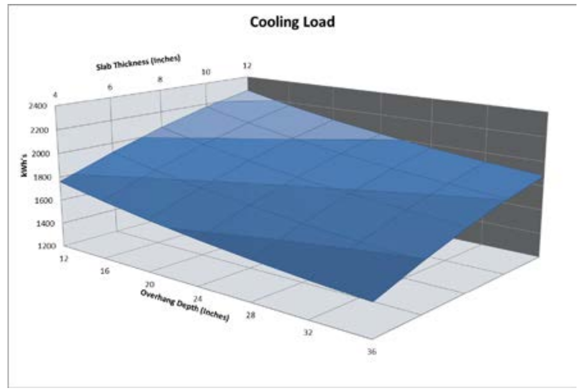


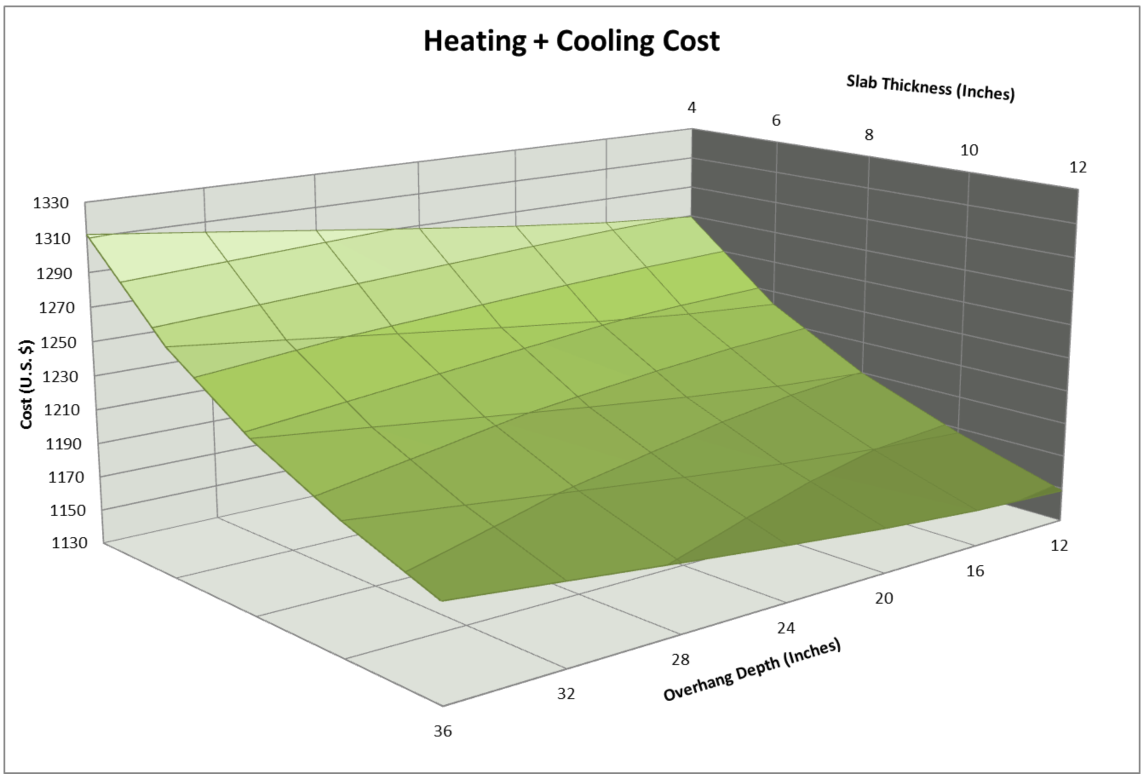


With a WWR of 18.9 the minimum cost of $1,180 occurs with a 12” Slab and a 12” Overhang.

25.2 WWR:

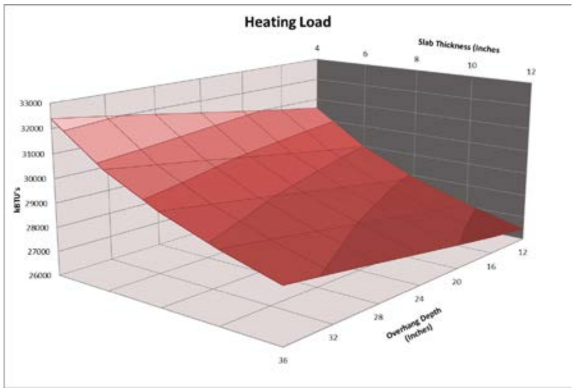


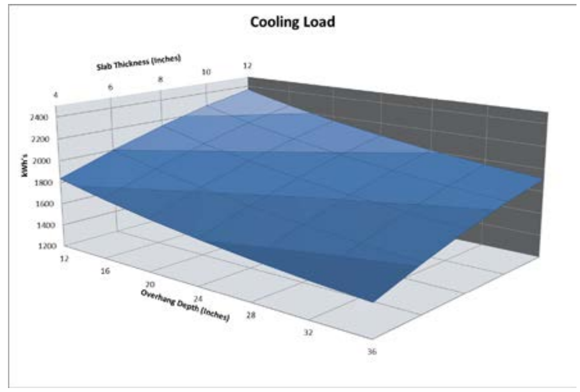


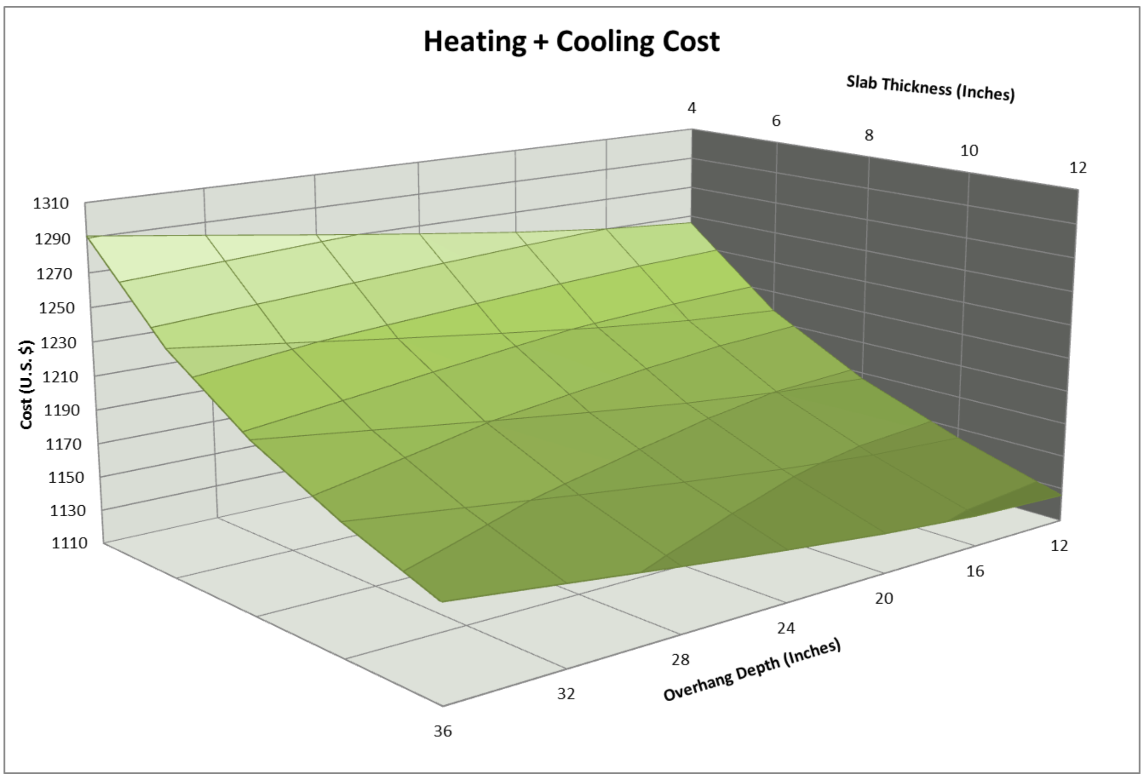


With a WWR of 25.2 the minimum cost of $1,148 occurs with a 12” Slab and a 12” Overhang.

<u>31.5 WWR:</u>



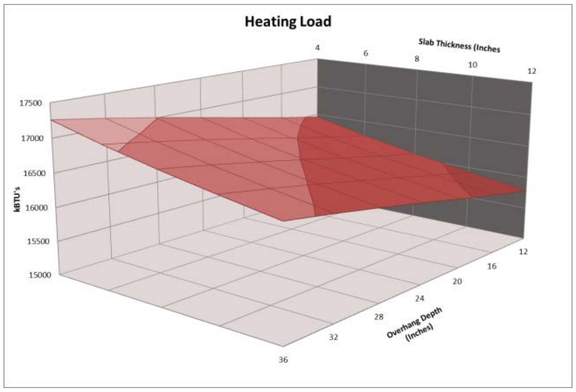


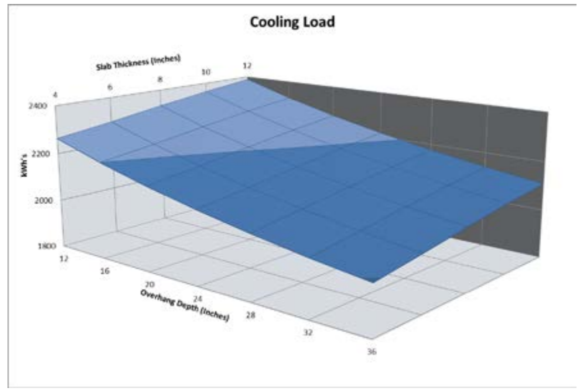


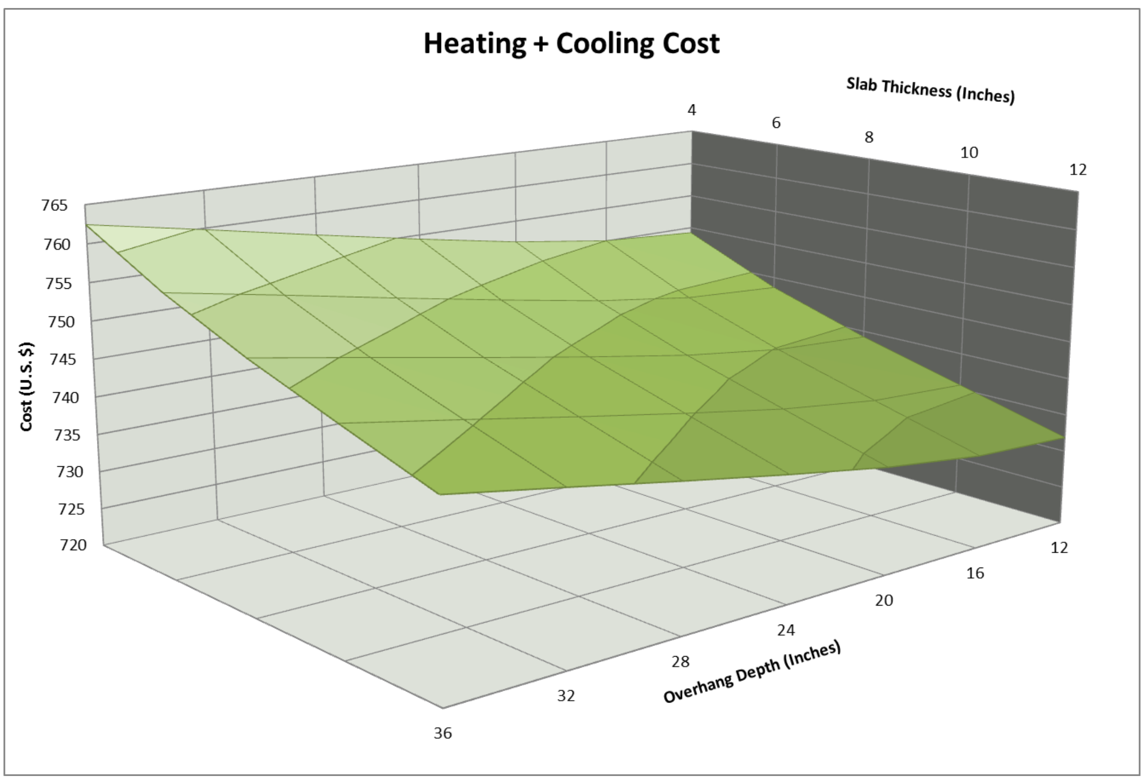
With a WWR of 25.2 the minimum cost of $1,125 occurs with a 12” Slab and a 12” Overhang.

Energy Star – Passive House Avg.

<u>**12.6 WWR:**</u>

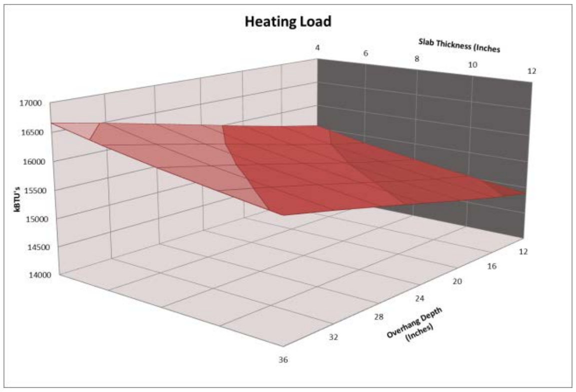


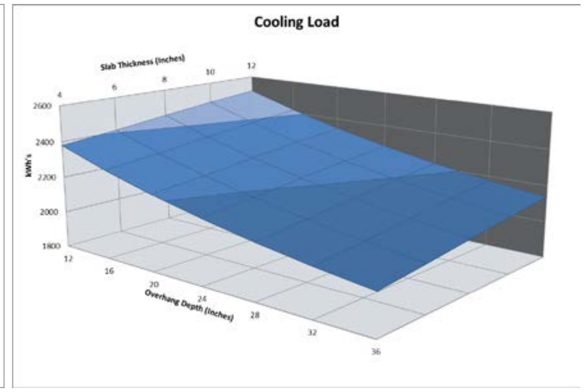


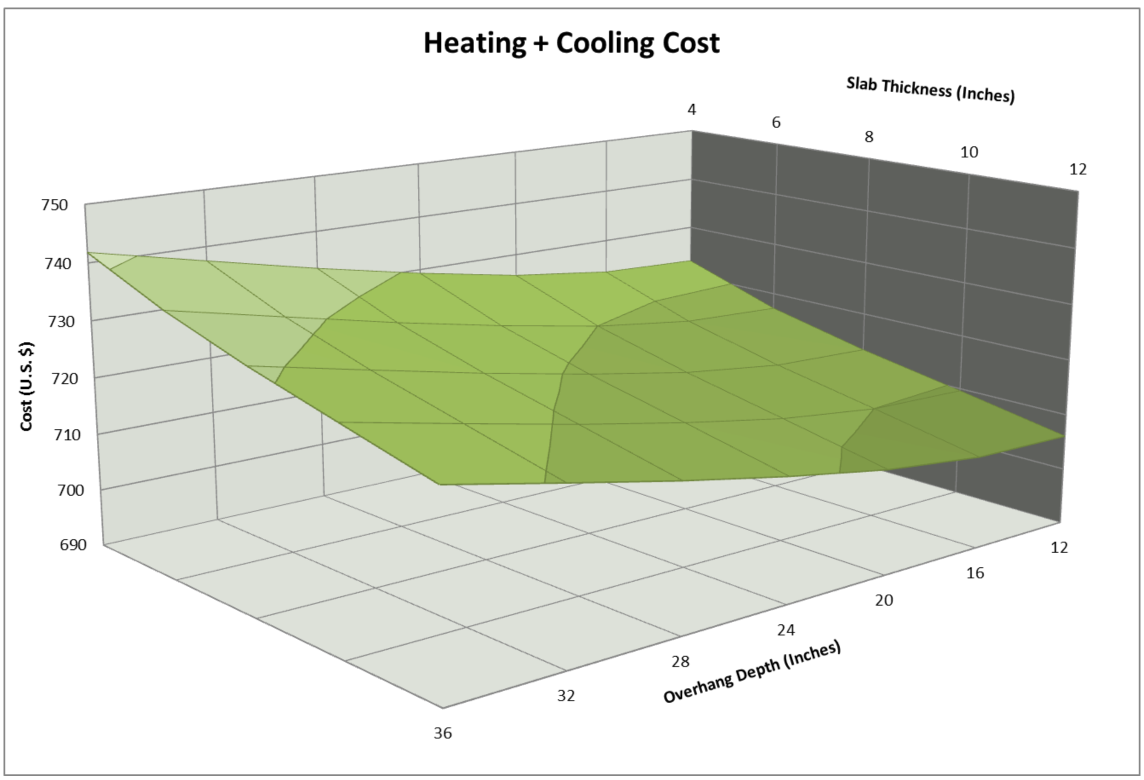


With a WWR of 12.6 the minimum cost of $731 occurs with a 12" Slab and a 12" Overhang.

18.9 WWR:

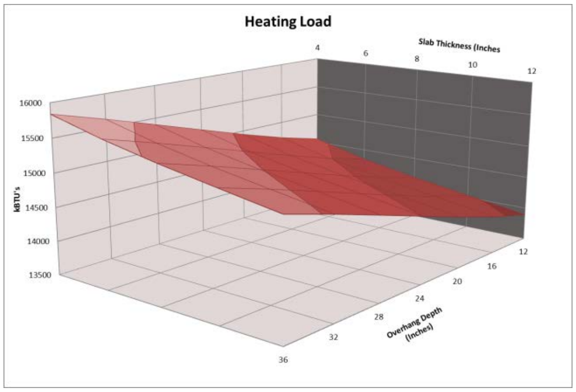


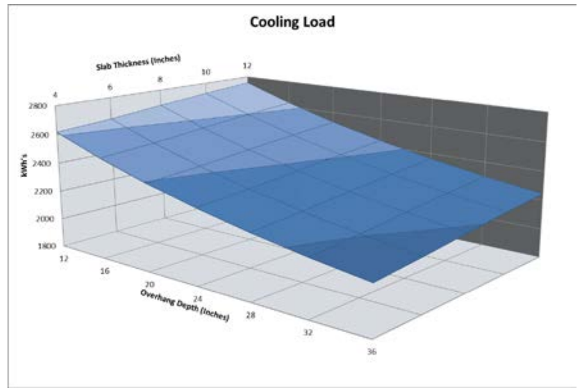


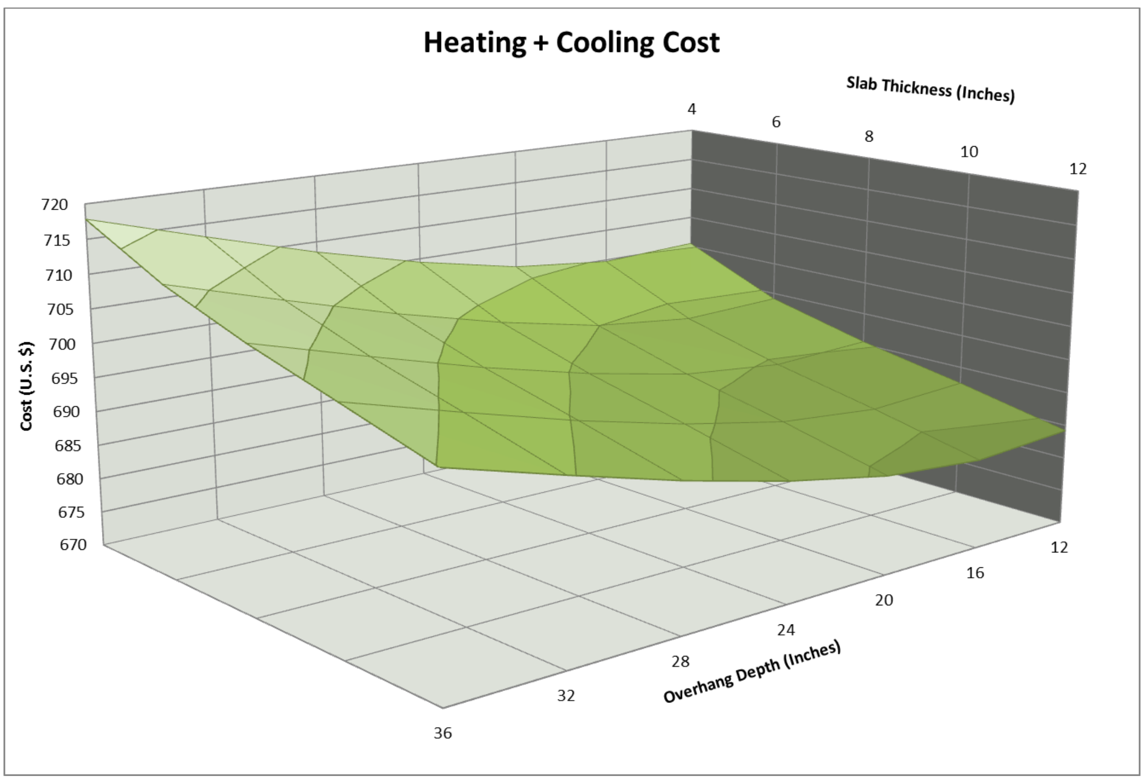


With a WWR of 18.9 the minimum cost of $706 occurs with a 12" Slab and a 12" Overhang.

25.2 WWR:

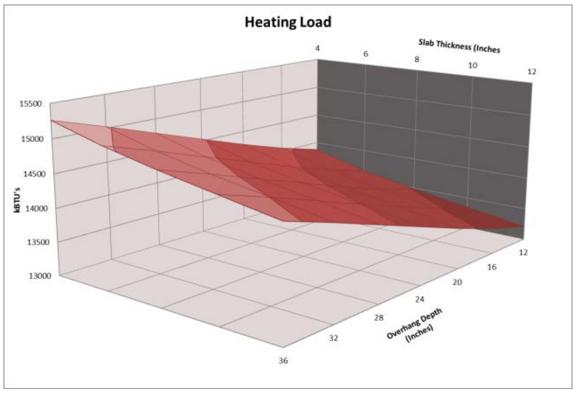


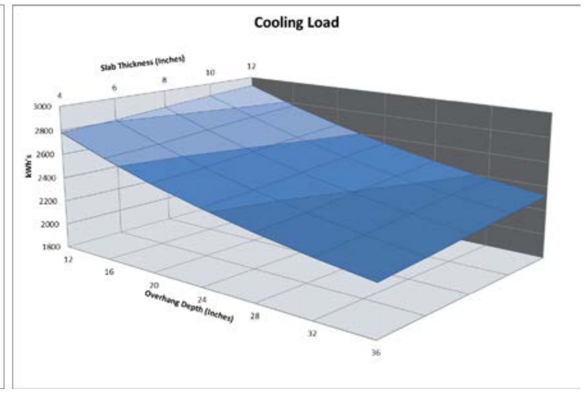


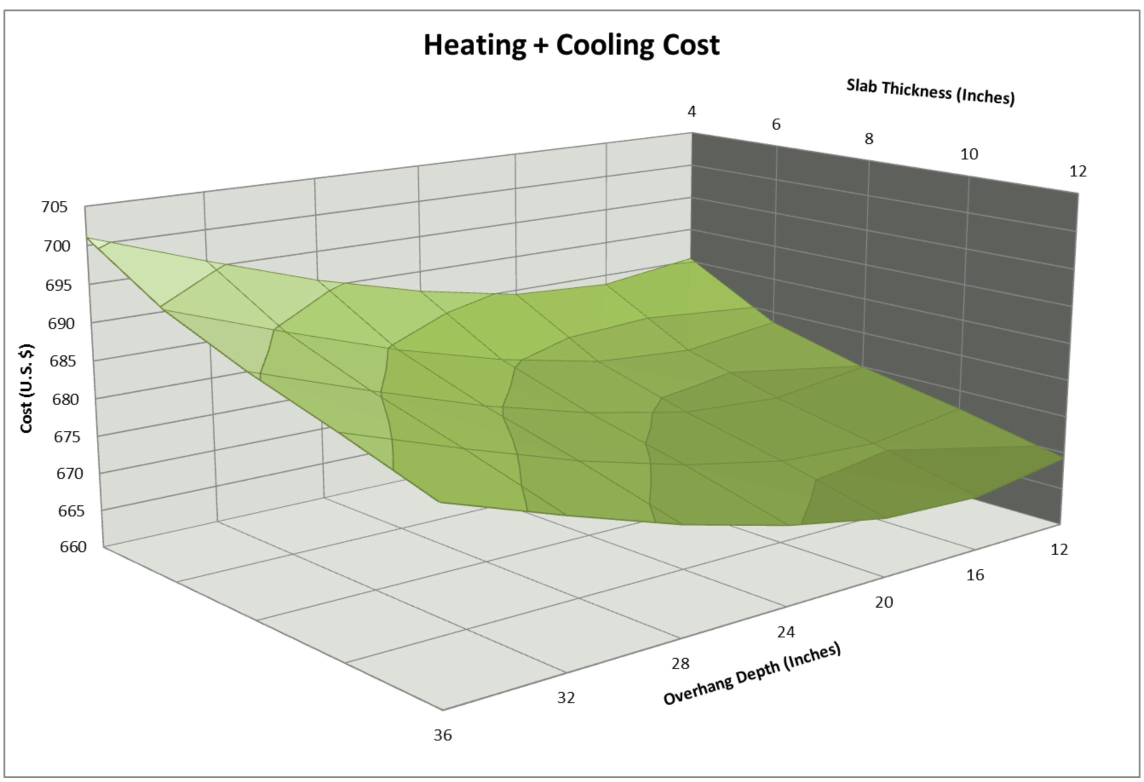


With a WWR of 25.2 the minimum cost of $683 occurs with a 12" Slab and a 16" Overhang.

31.5 WWR:



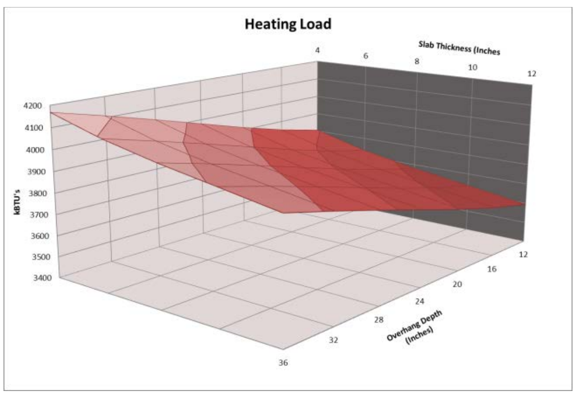


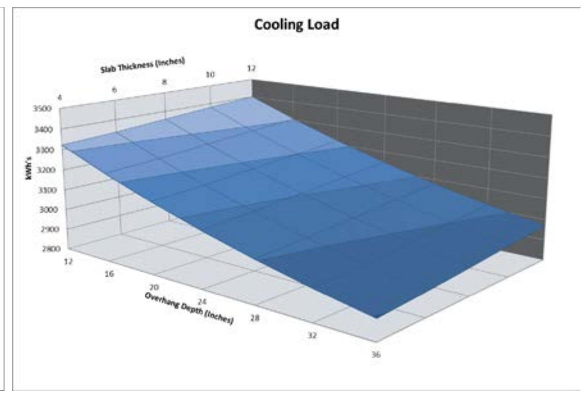


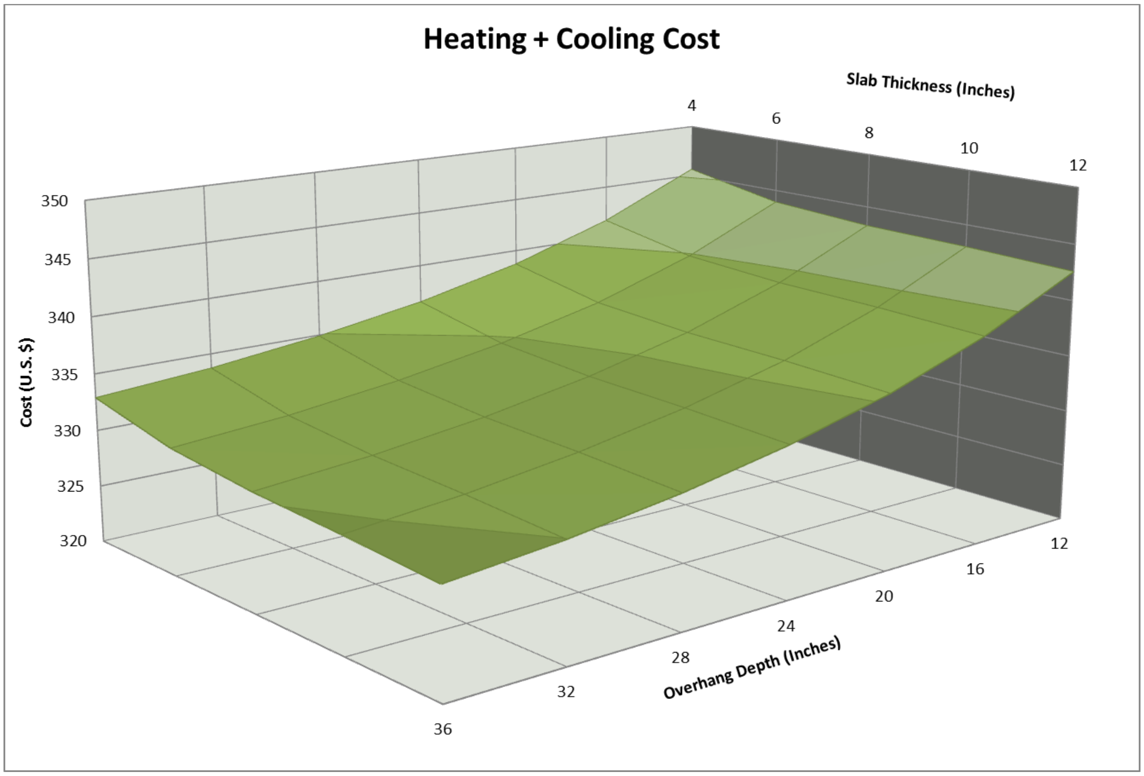
With a WWR of 31.5 the minimum cost of $667 occurs with a 12” Slab and a 16” Overhang.

Passive House

12.6 WWR:

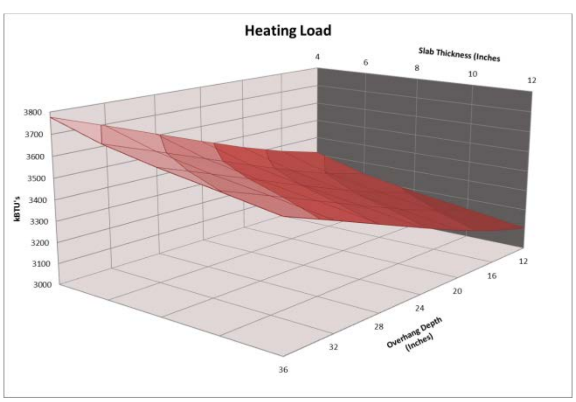


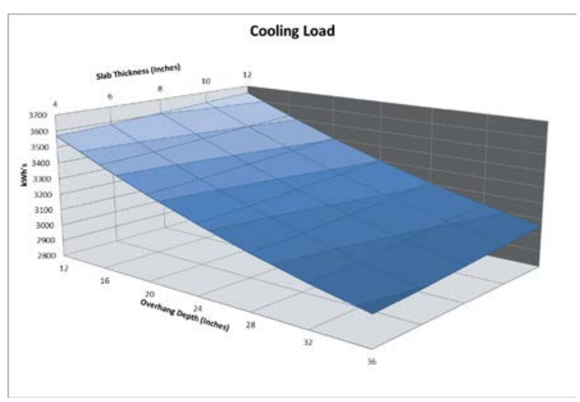


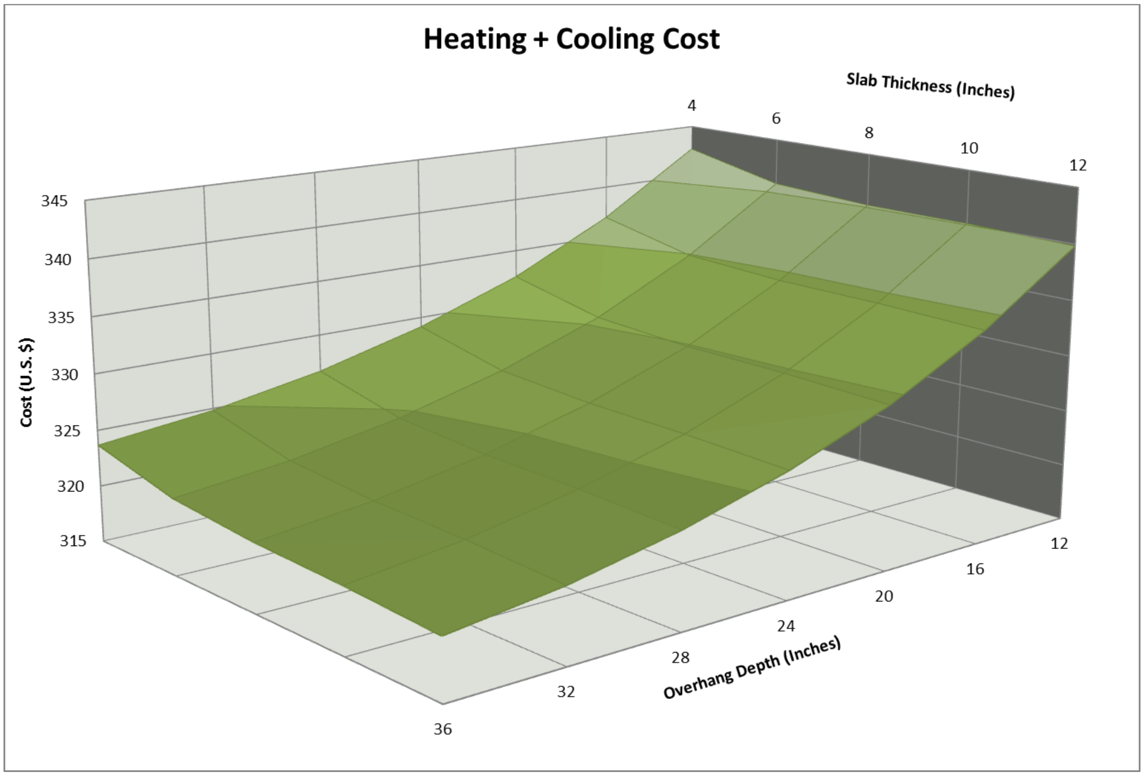


With a WWR of 12.6 the minimum cost of $329 occurs with a 12” Slab and a 36” Overhang.

18.9 WWR:

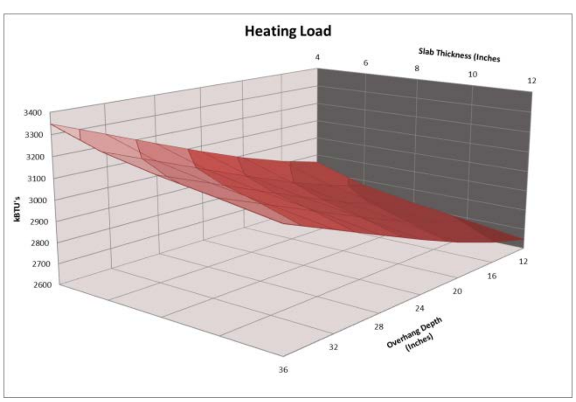


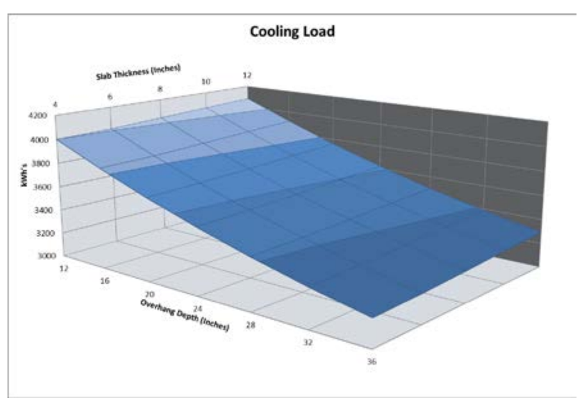


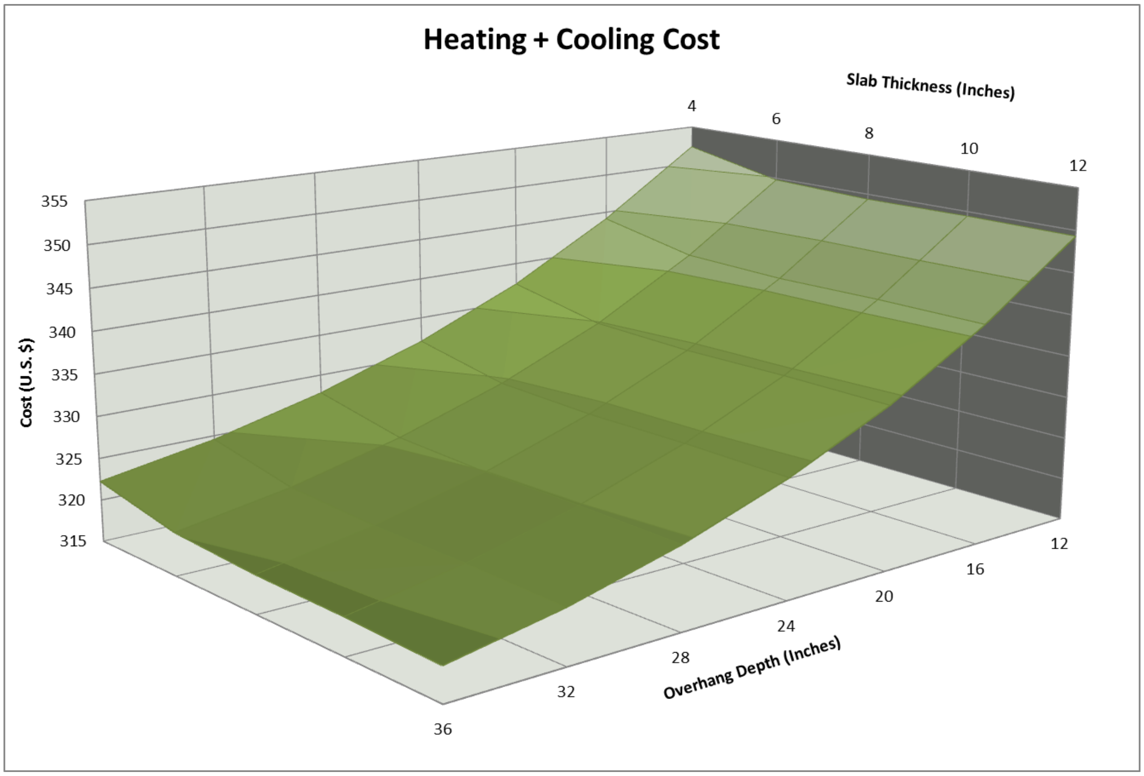


With a WWR of 18.9 the minimum cost of \$320 occurs with a 12" Slab and a 36" Overhang.

25.2 WWR:

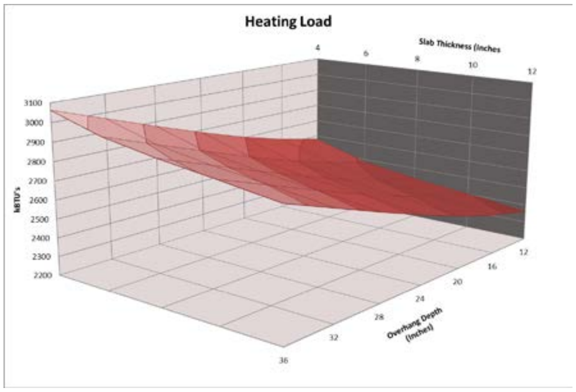


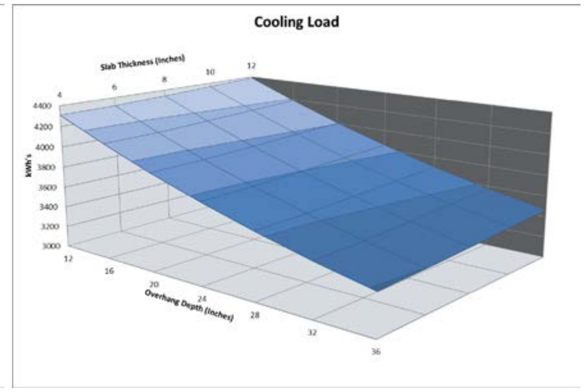


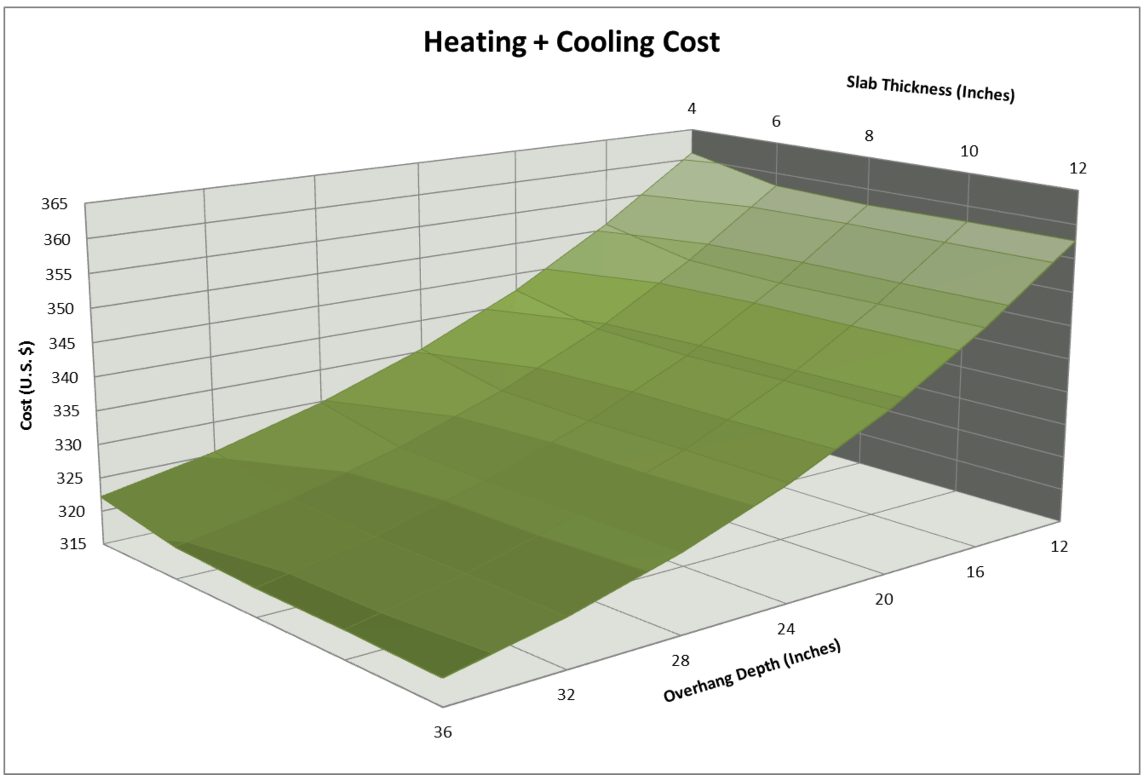


With a WWR of 25.2 the minimum cost of $318 occurs with a 12” Slab and a 36” Overhang.

<u>31.5 WWR:</u>





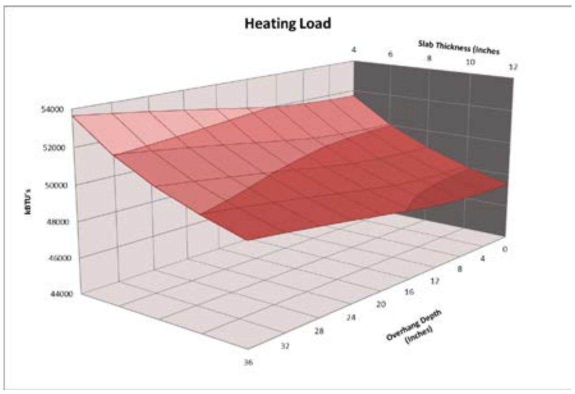


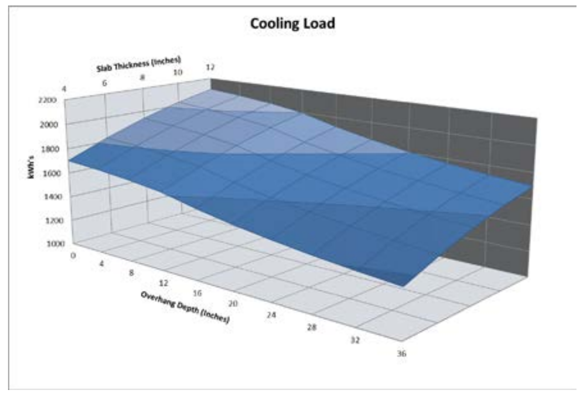
With a WWR of 31.5 the minimum cost of $318 occurs with a 12” Slab and a 36” Overhang.

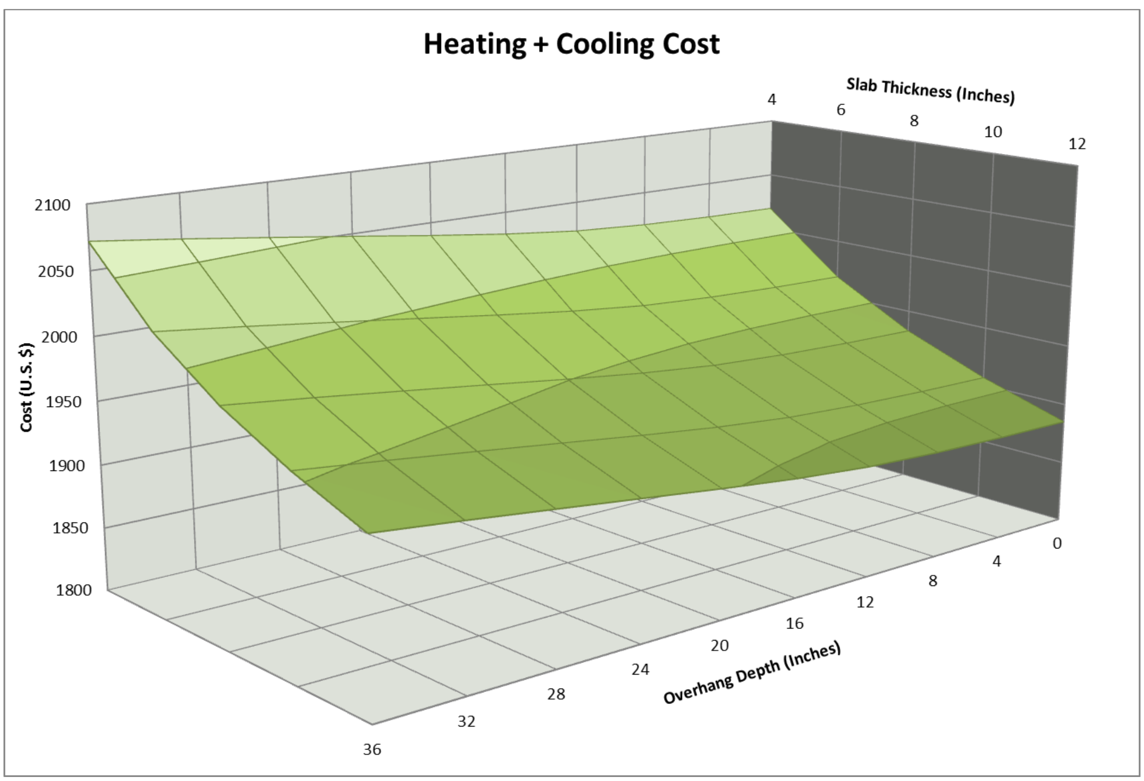
Saltbox

IECC

12.4 WWR:

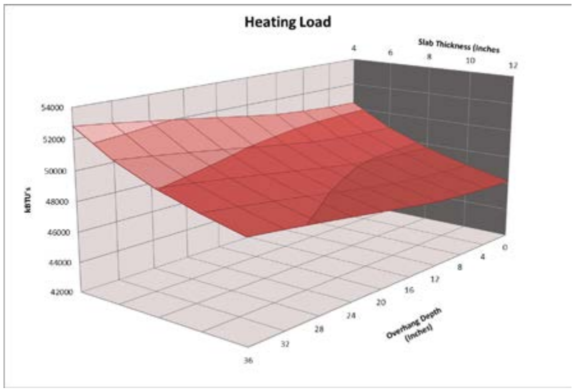


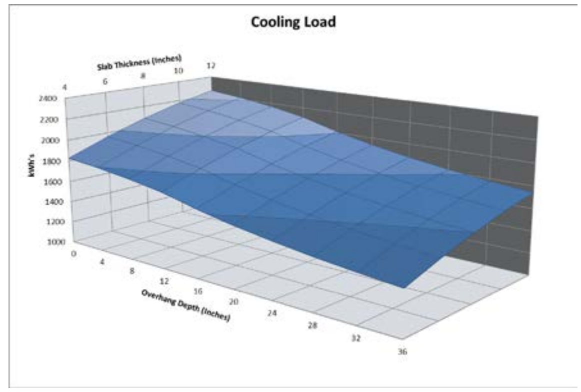


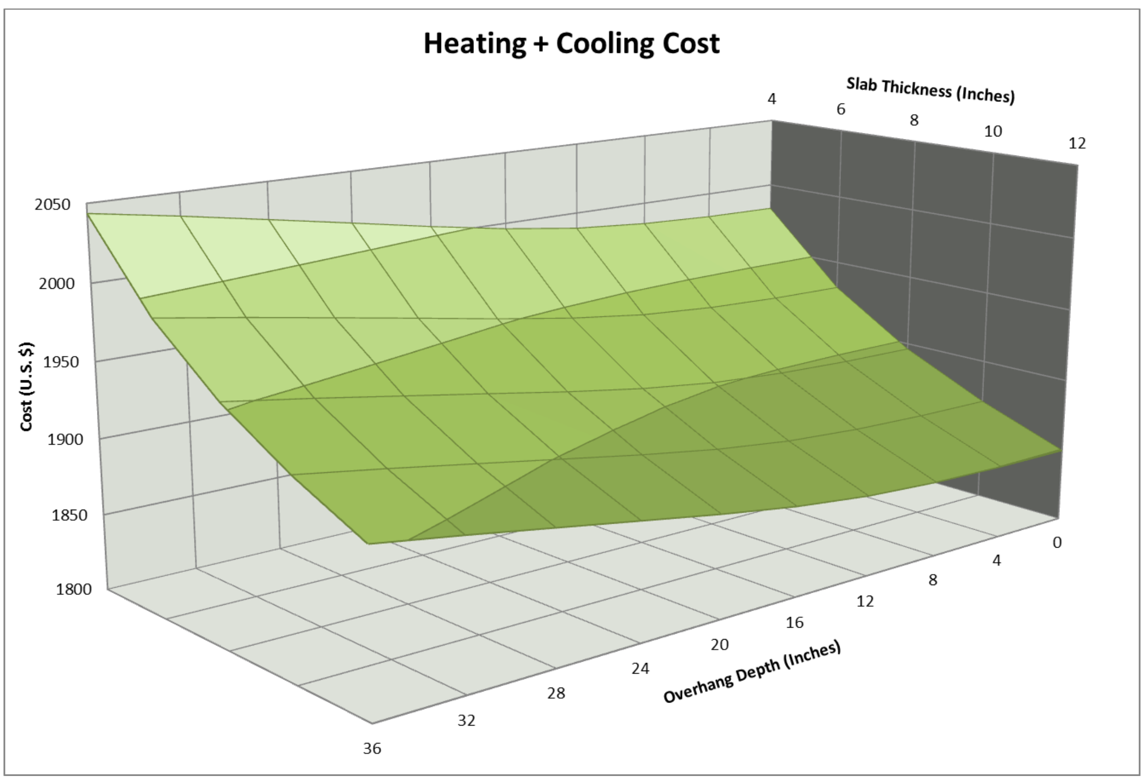


With a WWR of 12.4 the minimum cost of $1,885 occurs with a 12" Slab and a 0" Overhang.

15.1 WWR:

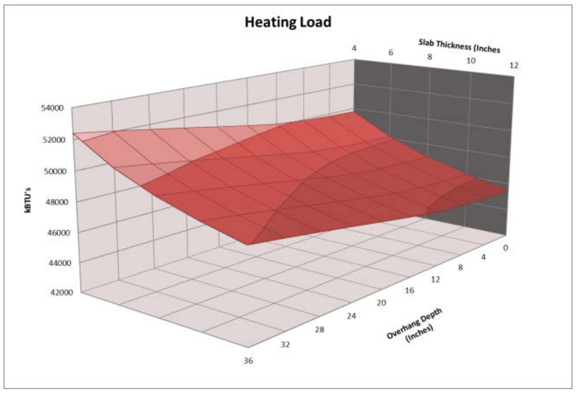


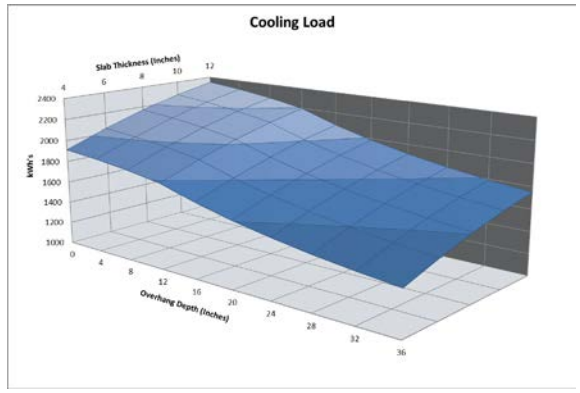


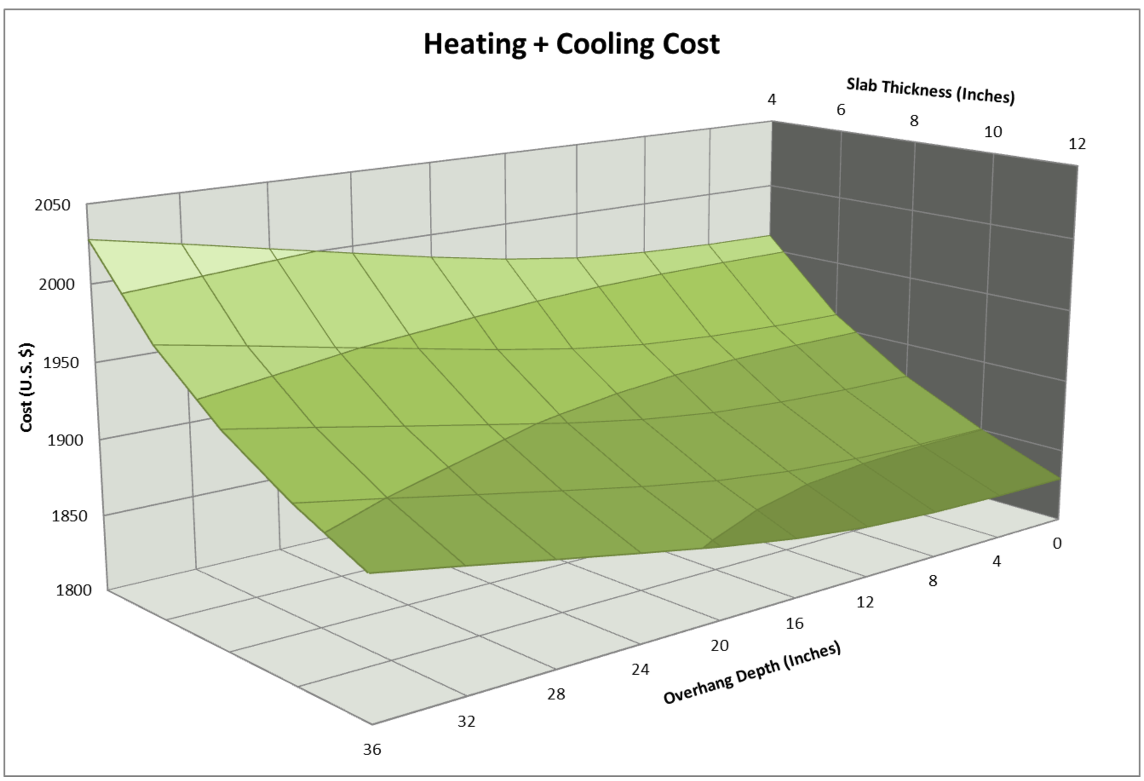


With a WWR of 15.1 the minimum cost of $1,849 occurs with a 12" Slab and a 0" Overhang.

17.8 WWR:

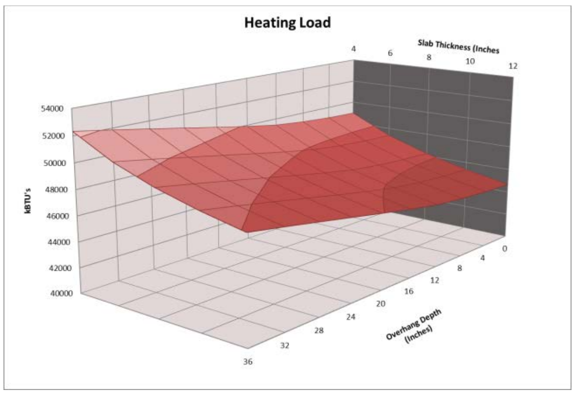


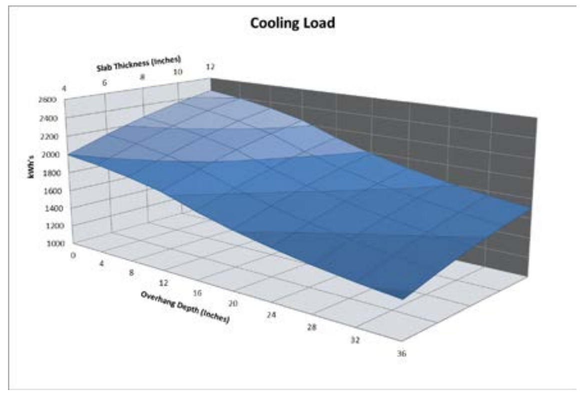


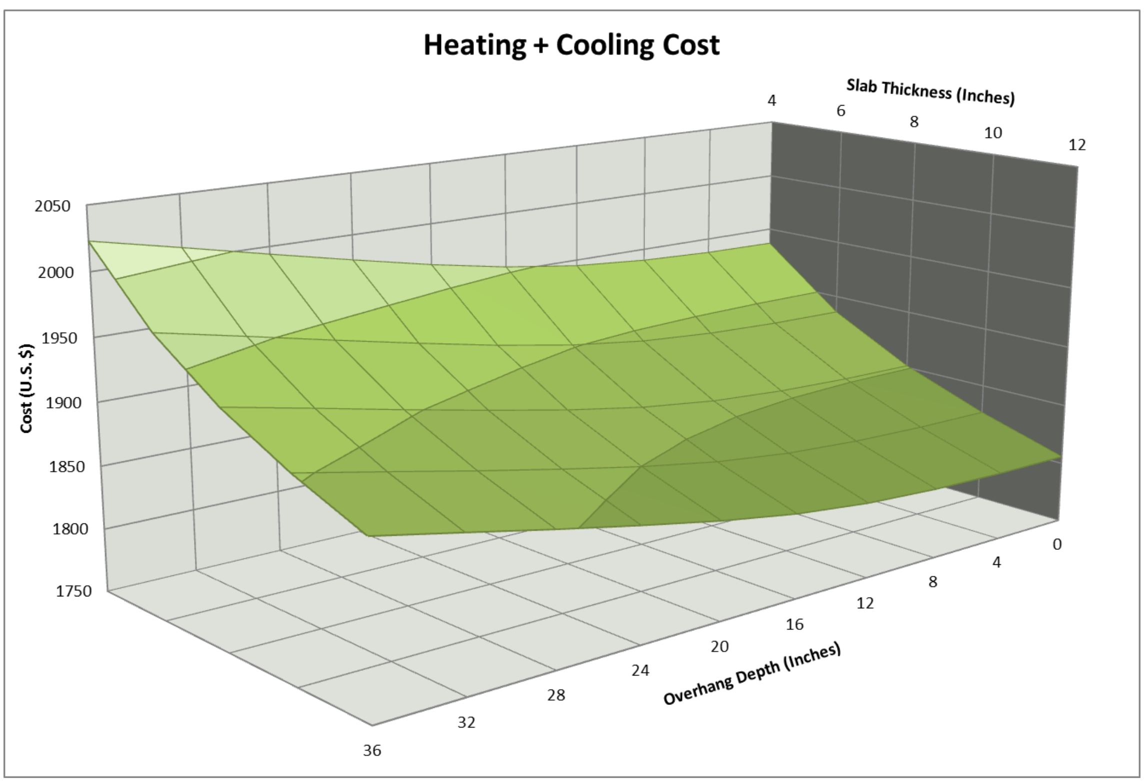


With a WWR of 17.8 the minimum cost of $1,829 occurs with a 12" Slab and a 0" Overhang.

20.6 WWR:

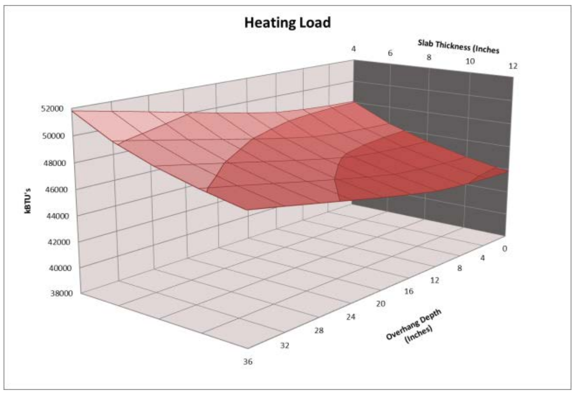

Heating Load
Slab Thickness (Inches
4
6
8
10
12
54000
52000
50000
48000
46000
44000
42000
40000
kBTU's
0
4
8
12
16
20
24
28
32
36
Overhang Depth (Inches)

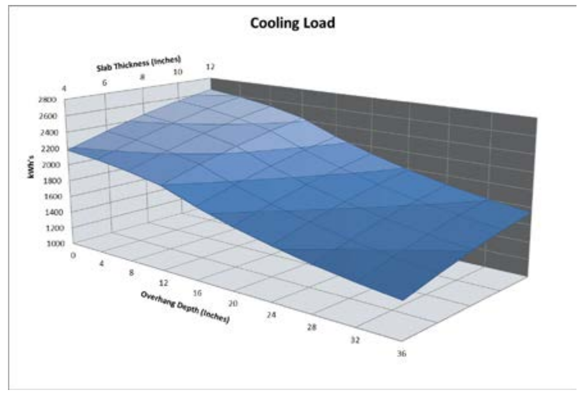

Cooling Load
Slab Thickness (Inches)
4
6
8
10
12
2600
2400
2200
2000
1800
1600
1400
1200
1000
kWh's
0
4
8
12
16
20
24
28
32
36
Overhang Depth (Inches)

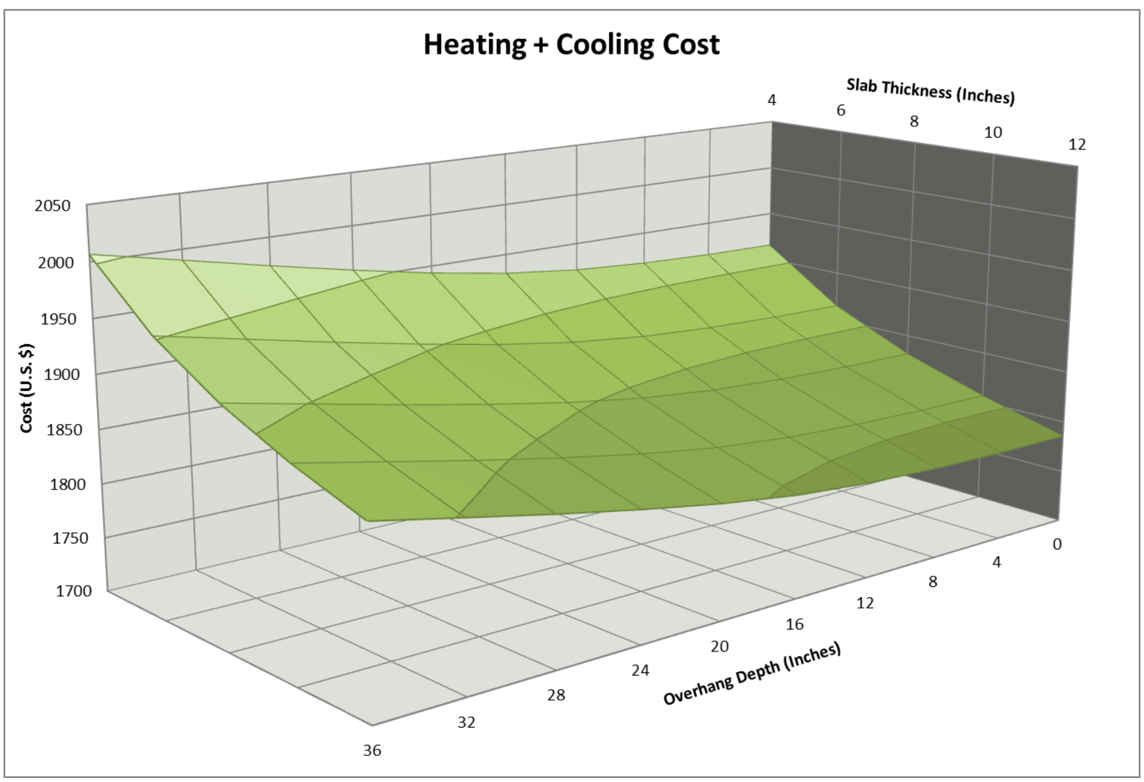

Heating + Cooling Cost
Slab Thickness (Inches)
4
6
8
10
12
2050
2000
1950
1900
1850
1800
1750
Cost (U.S.$)
0
4
8
12
16
20
24
28
32
36
Overhang Depth (Inches)

With a WWR of 20.6 the minimum cost of $1,805 occurs with a 12” Slab and a 0” Overhang.

23.3 WWR:

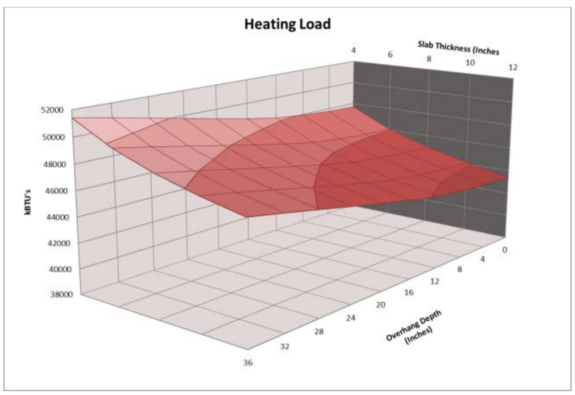


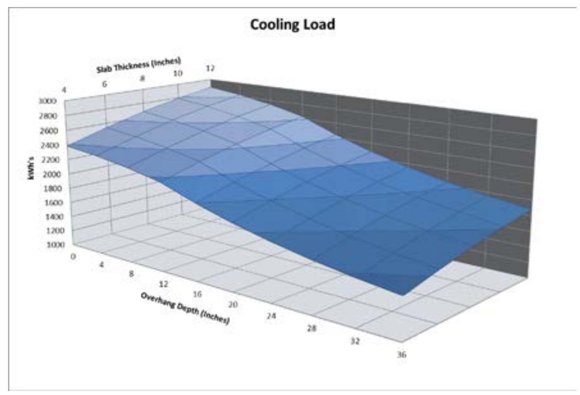


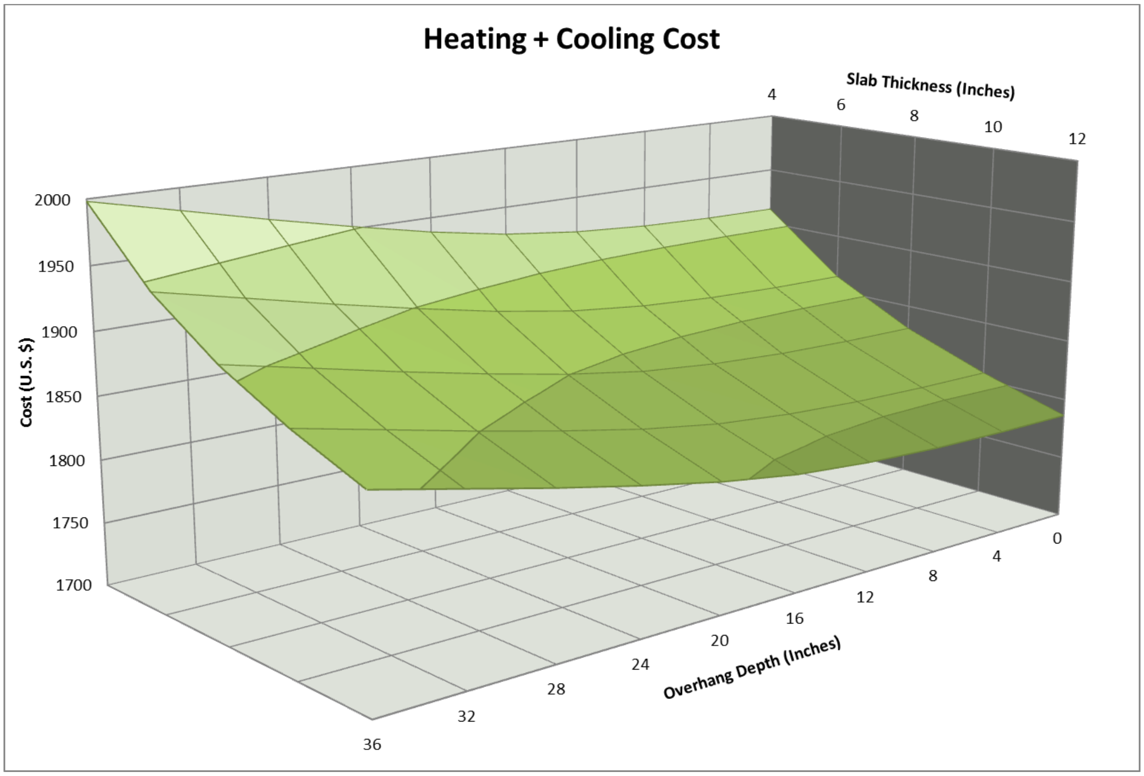


With a WWR of 23.3 the minimum cost of $1,785 occurs with a 12” Slab and a 0” Overhang.

26 WWR:



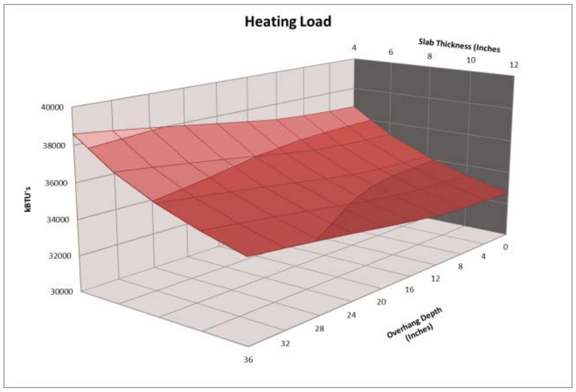


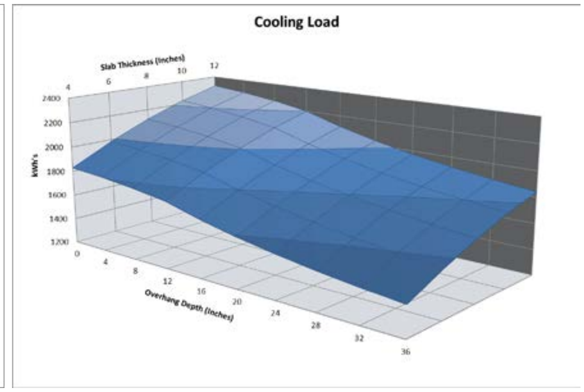


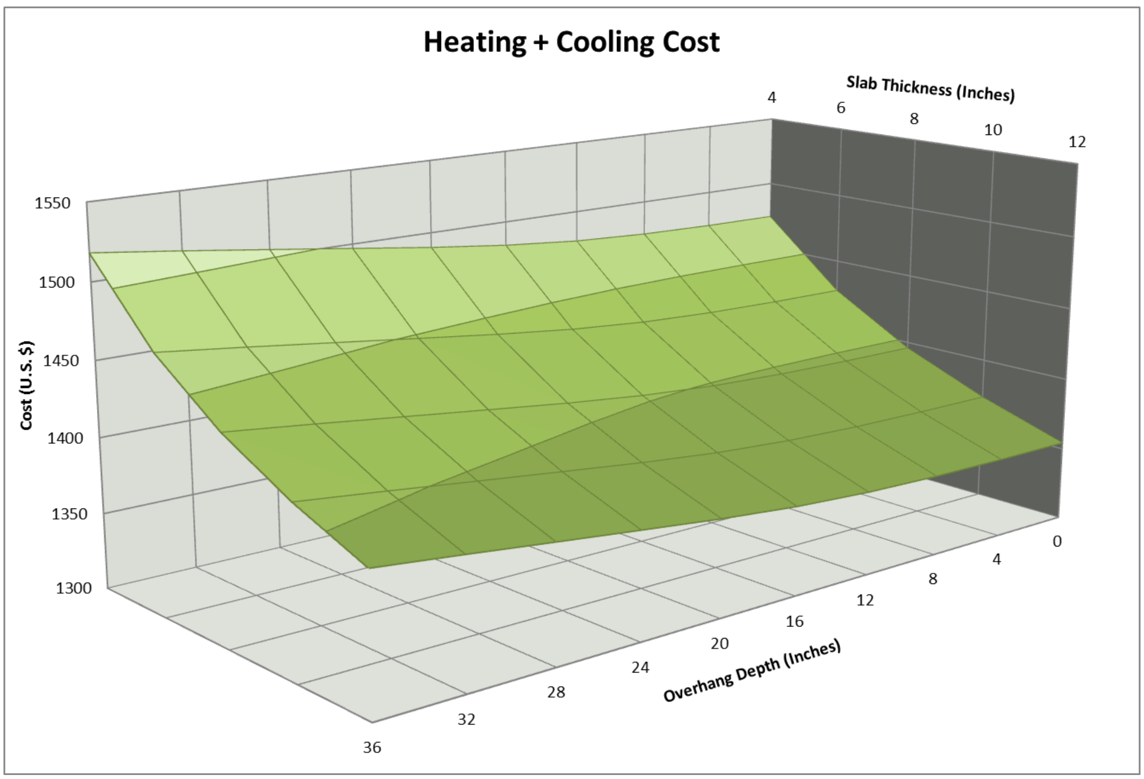
With a WWR of 26 the minimum cost of $1,785 occurs with a 12" Slab and a 4" Overhang.

Energy Star

12.4 WWR:

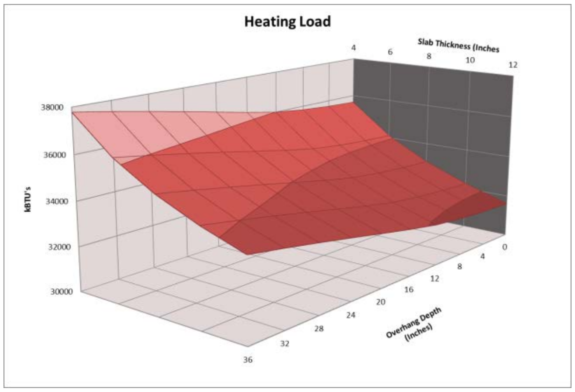


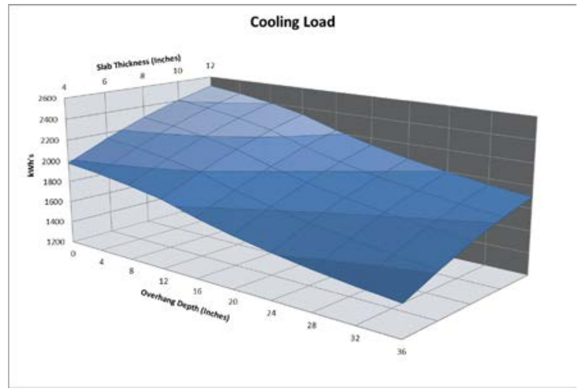


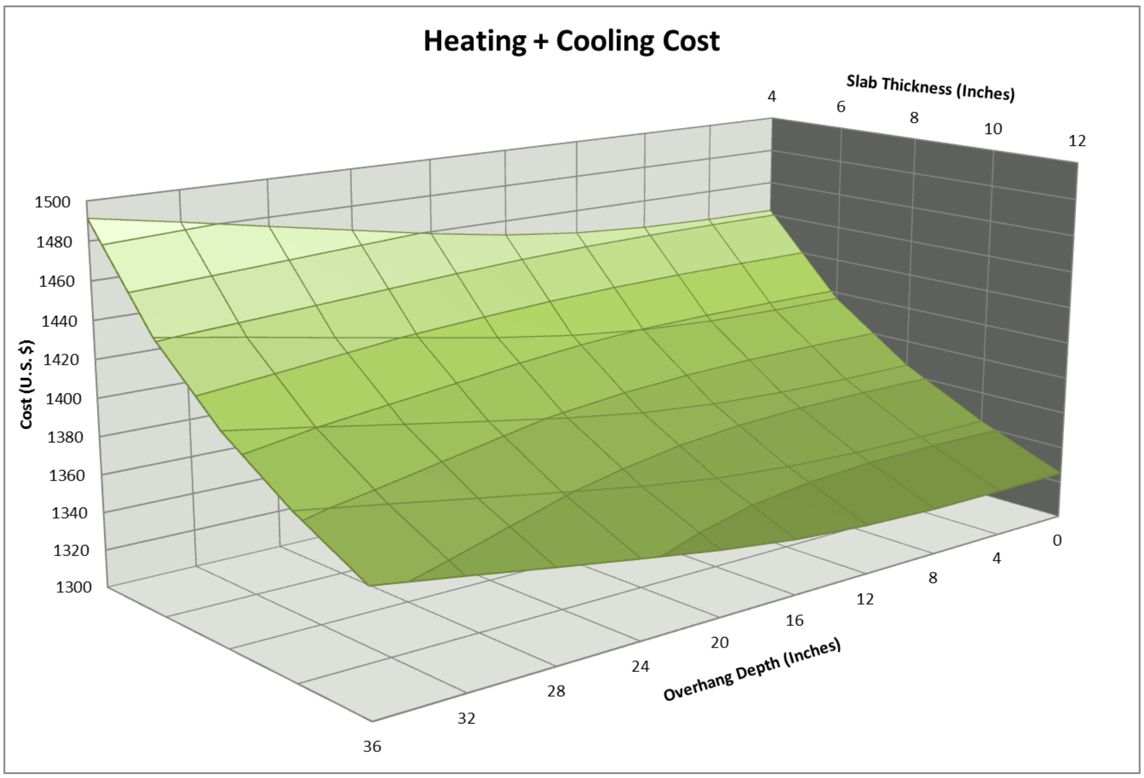


With a WWR of 12.4 the minimum cost of $1,354 occurs with a 12” Slab and a 4” Overhang.

<u>15.1 WWR:</u>

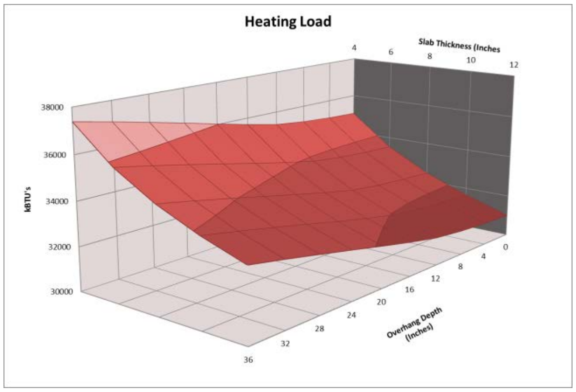


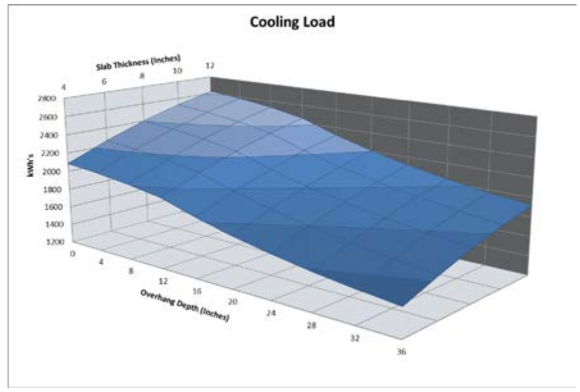


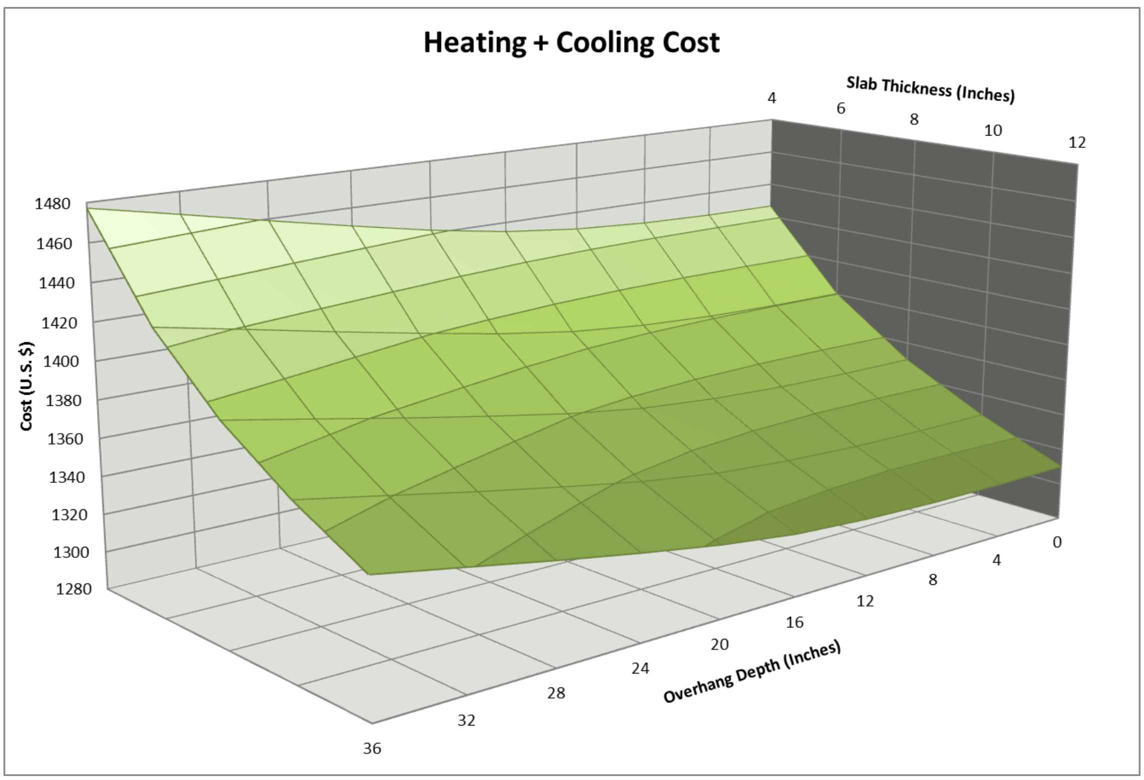


With a WWR of 15.1 the minimum cost of $1,324 occurs with a 12” Slab and a 4” Overhang.

<u>17.8 WWR:</u>

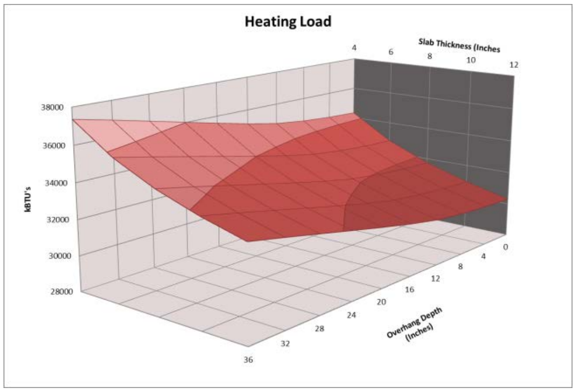


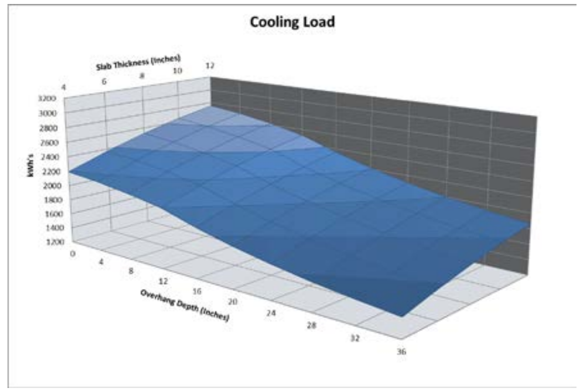


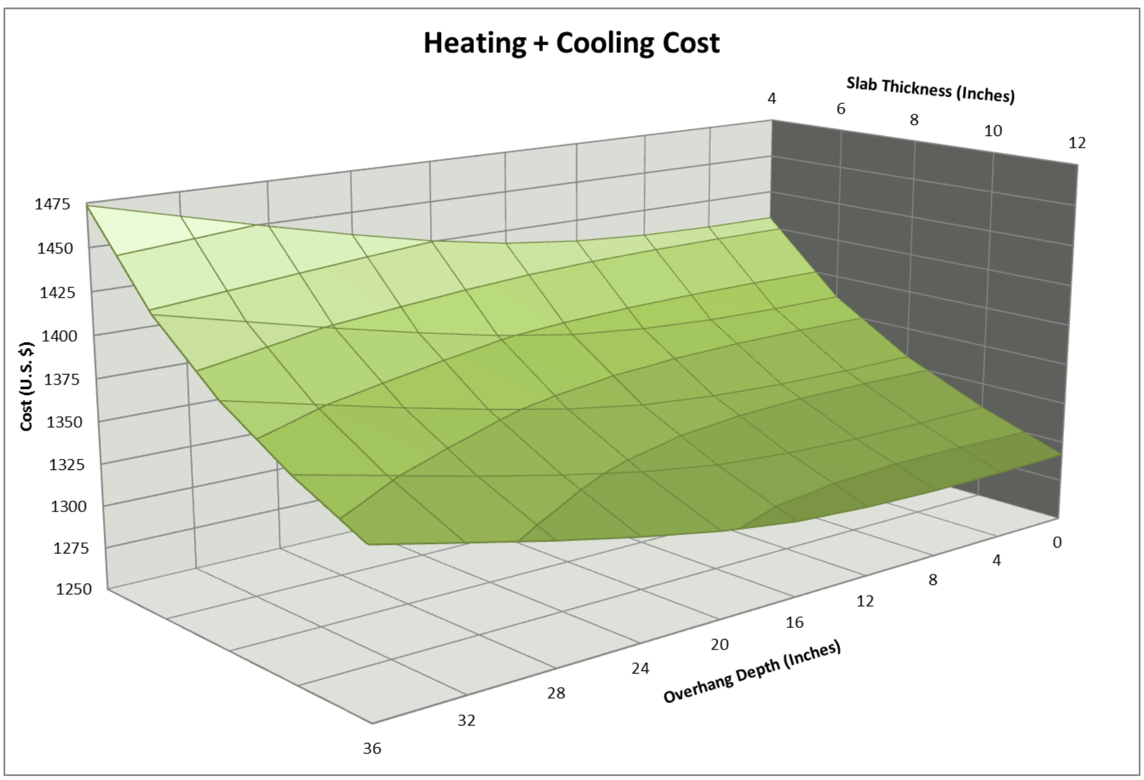


With a WWR of 17.8 the minimum cost of $1,309 occurs with a 12” Slab and a 4” Overhang.

20.6 WWR:

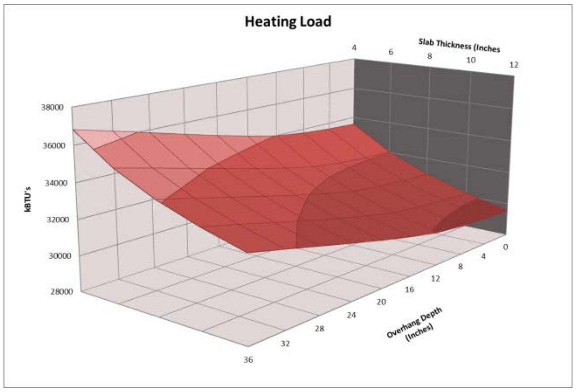


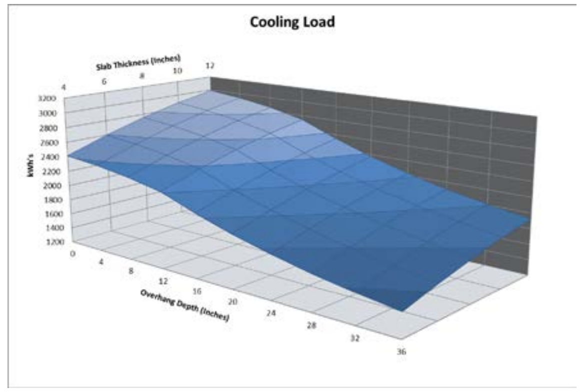


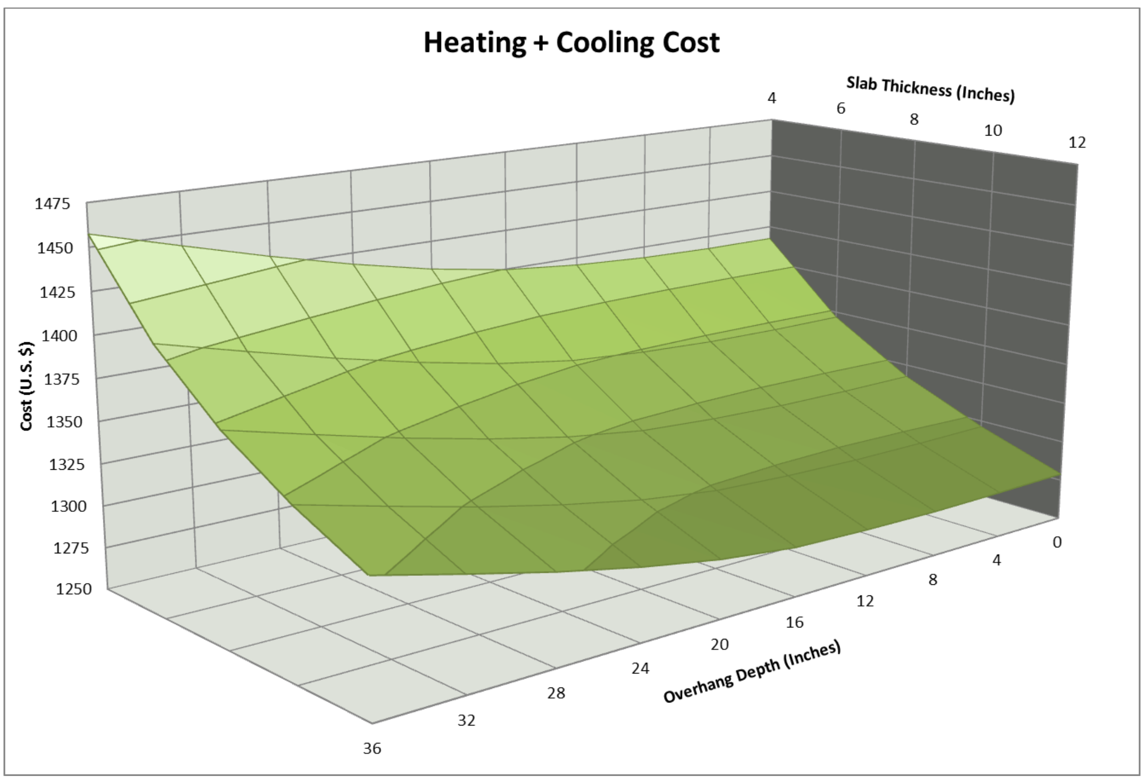


With a WWR of 20.6 the minimum cost of $1,290 occurs with a 12” Slab and a 8” Overhang.

23.3 WWR:

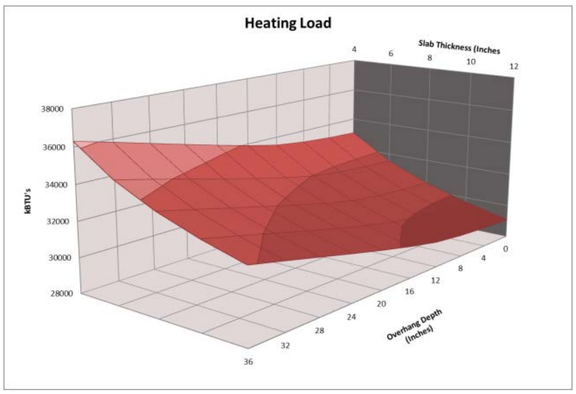


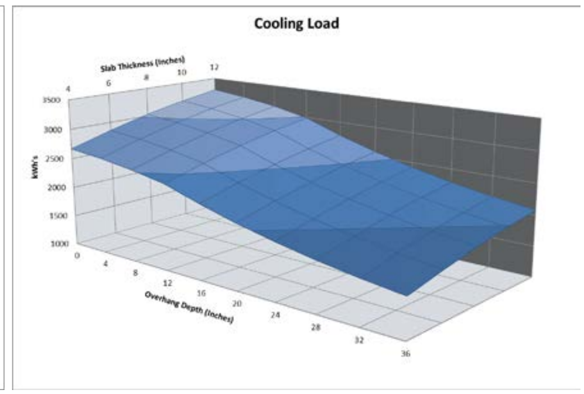


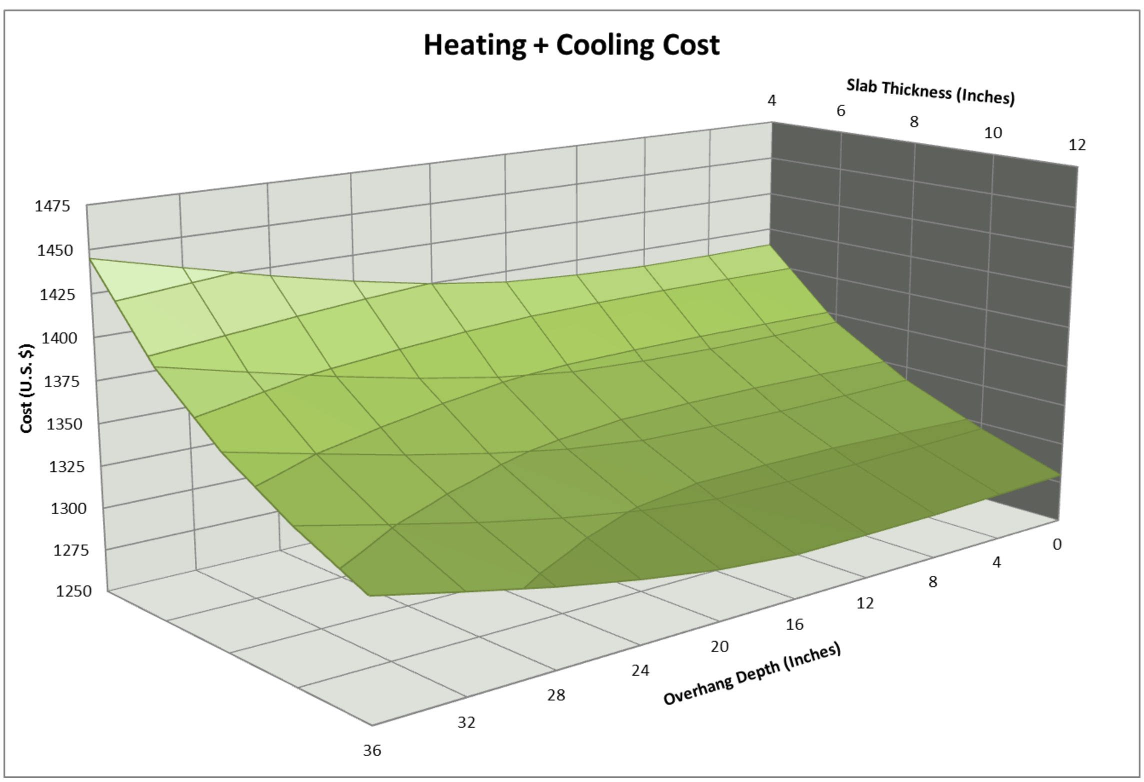


With a WWR of 23.3 the minimum cost of $1,277 occurs with a 12" Slab and a 8" Overhang.

26 WWR:



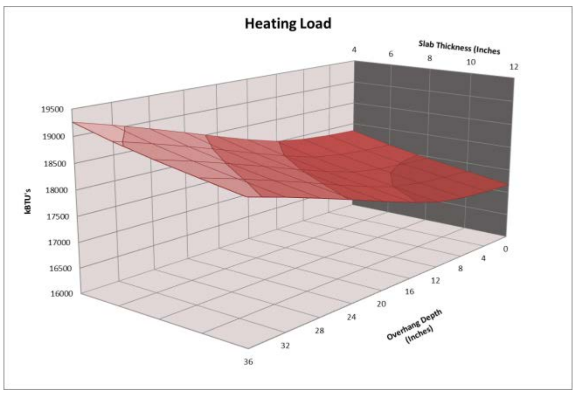


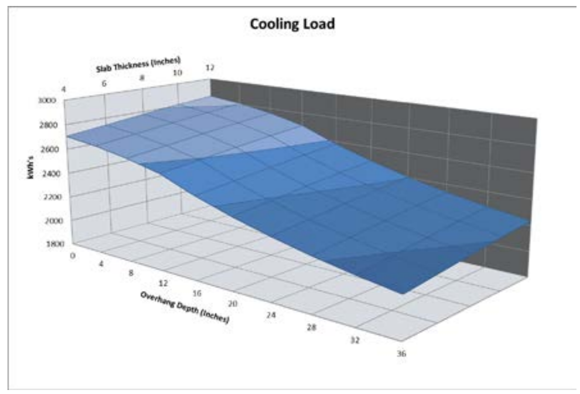


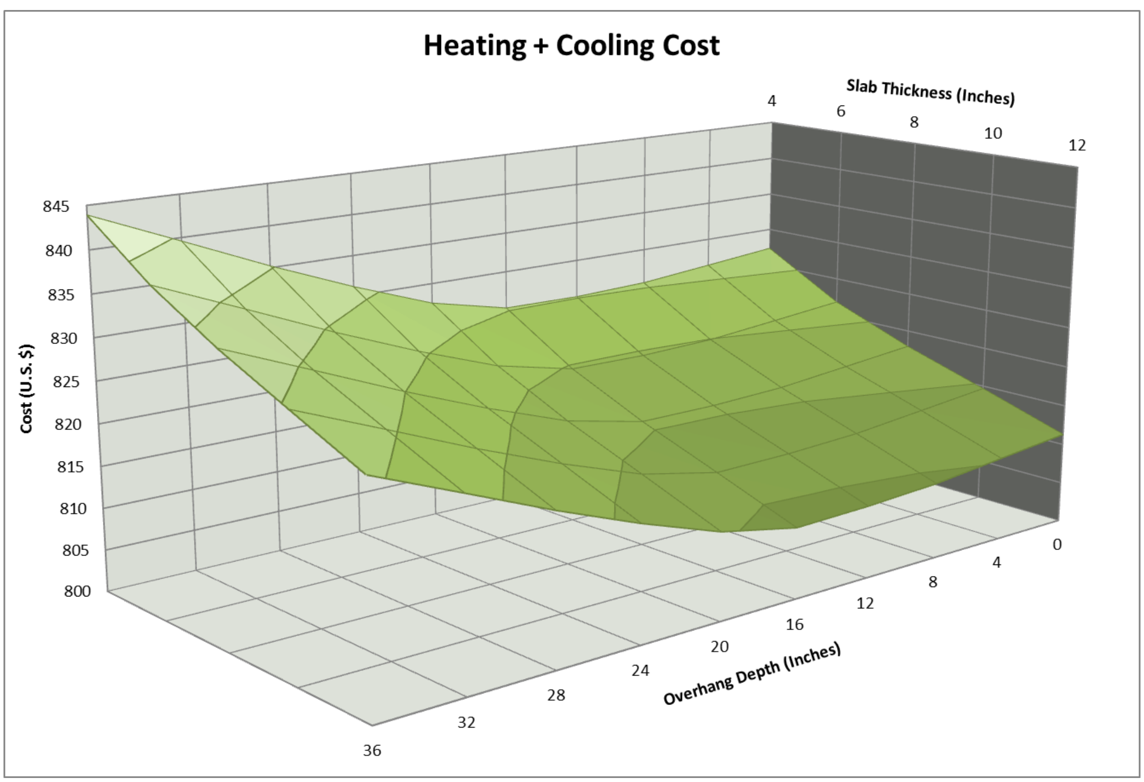
With a WWR of 26 the minimum cost of $1,277 occurs with a 12" Slab and a 12" Overhang.

Energy Star – Passive House Avg.

<u>12.4 WWR:</u>

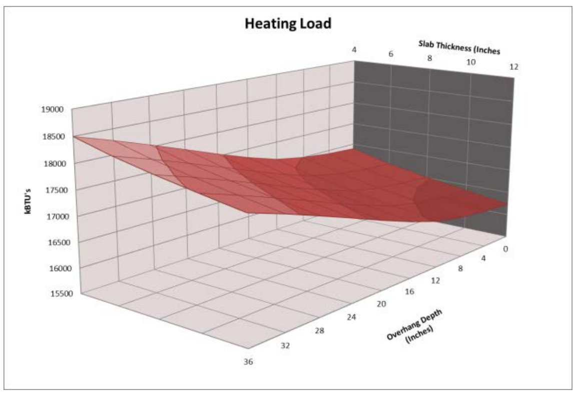


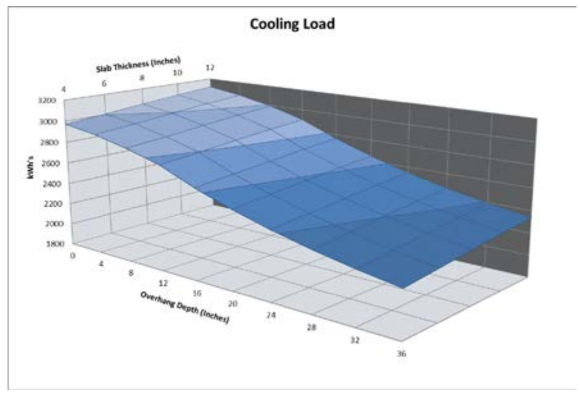


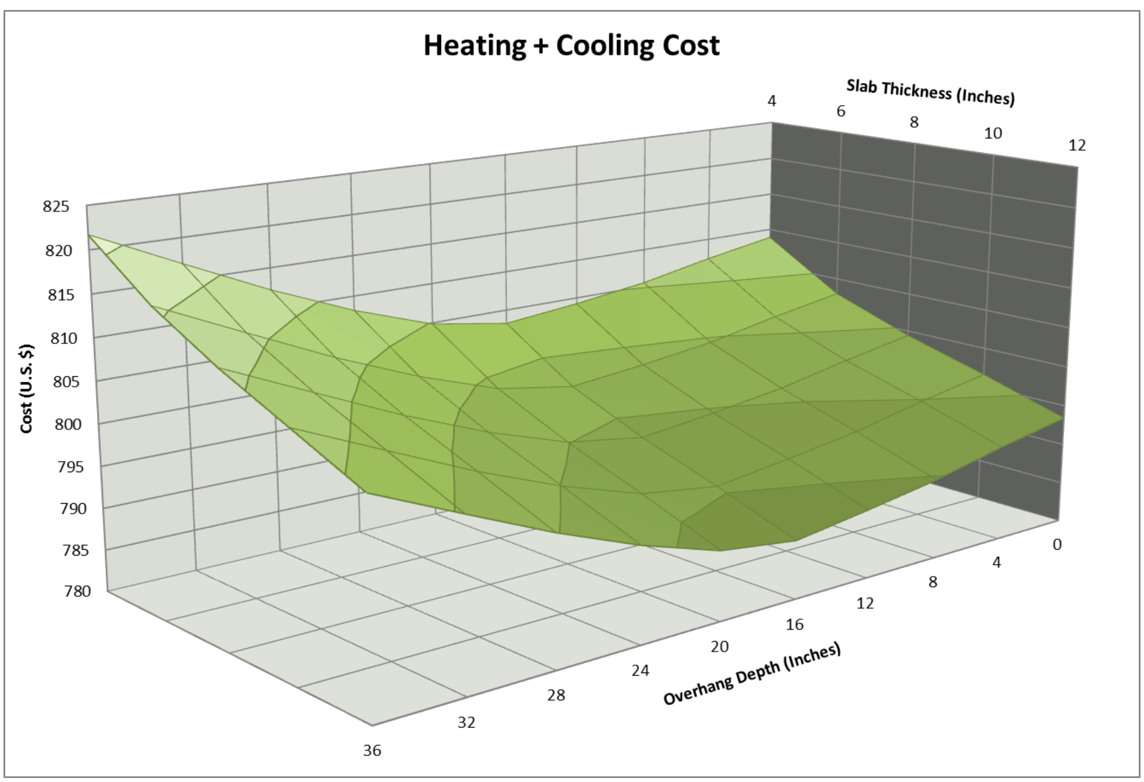


With a WWR of 12.4 the minimum cost of $808 occurs with a 12” Slab and a 12” Overhang.

15.1 WWR:

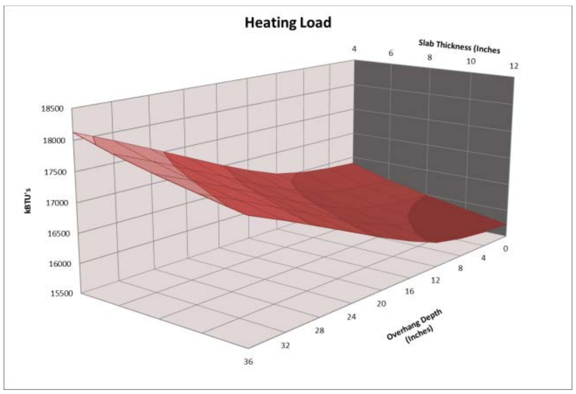


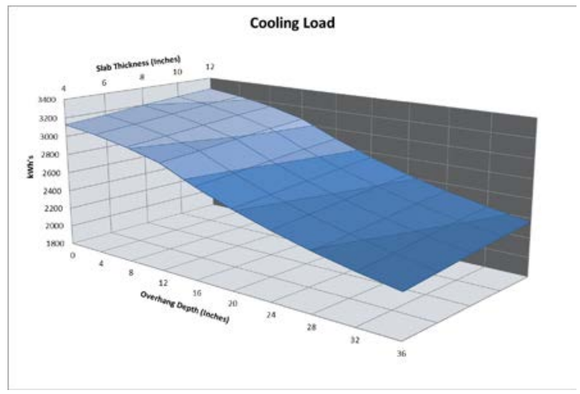


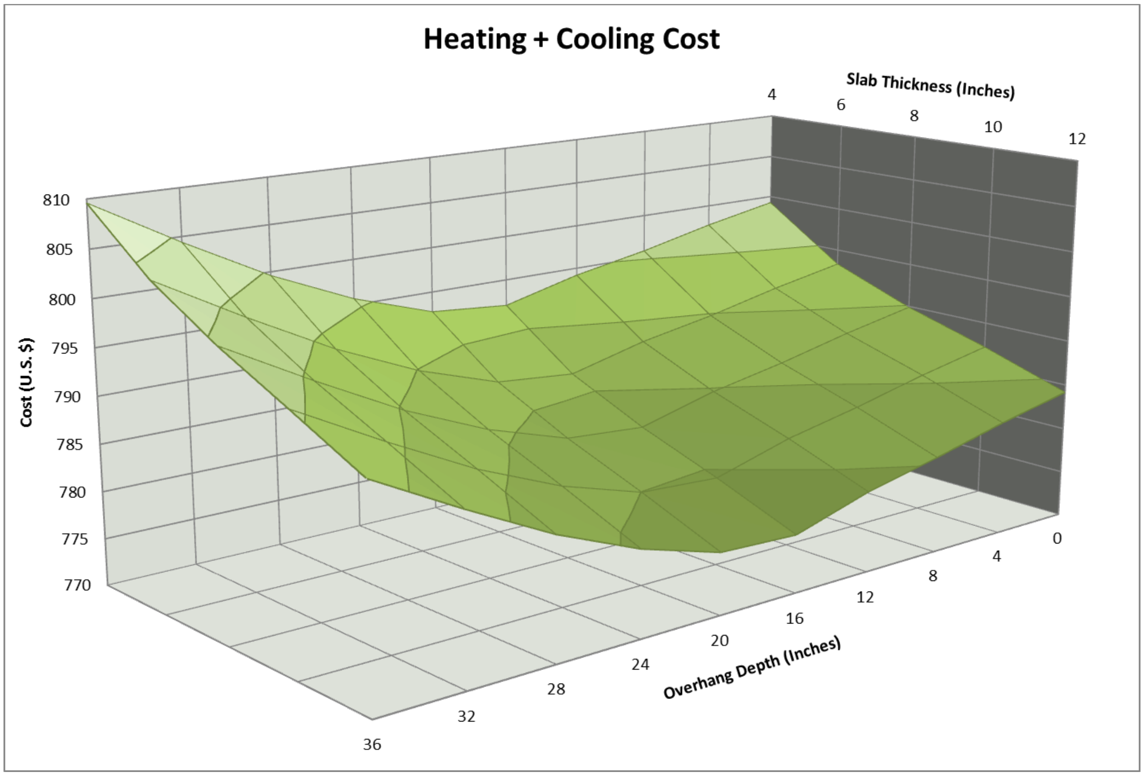


With a WWR of 15.1 the minimum cost of $787 occurs with a 12" Slab and a 16" Overhang.

17.8 WWR:

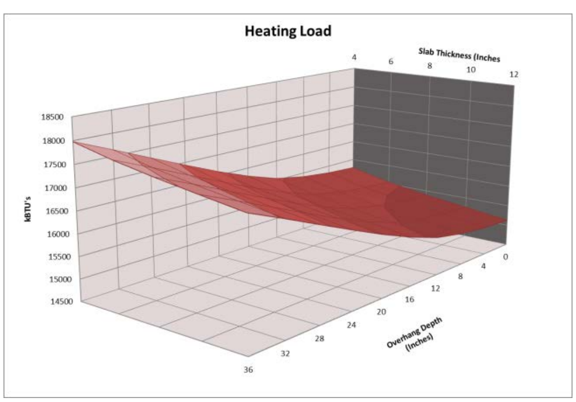


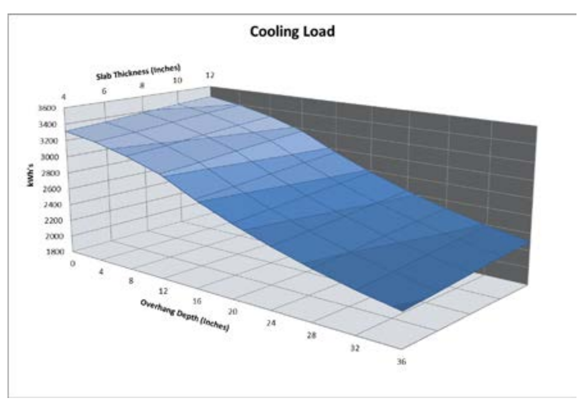


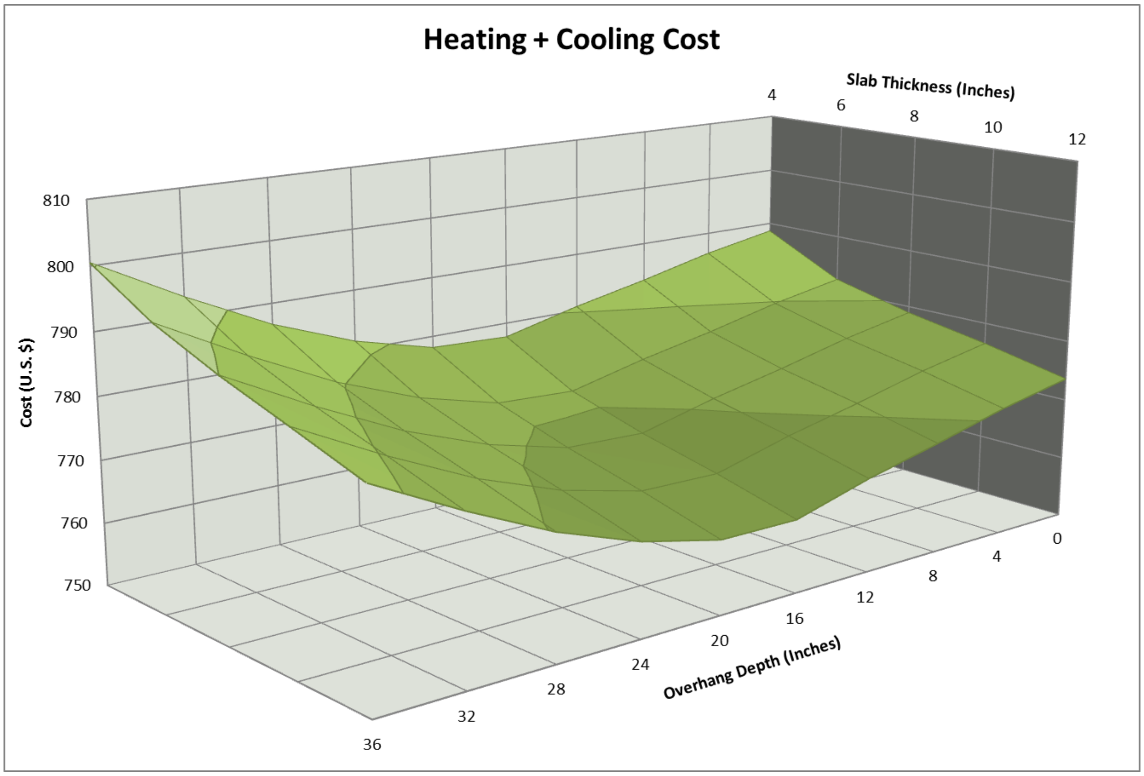


With a WWR of 17.8 the minimum cost of $776 occurs with a 12” Slab and a 16” Overhang.

20.6 WWR:

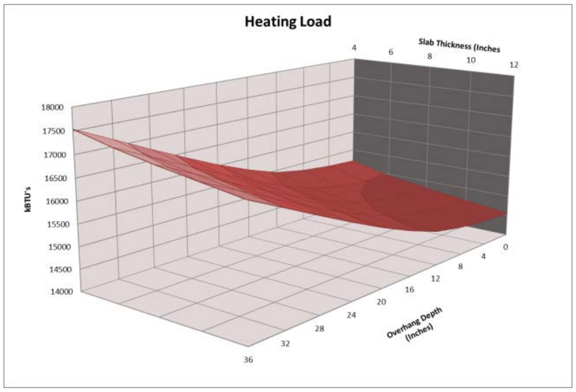


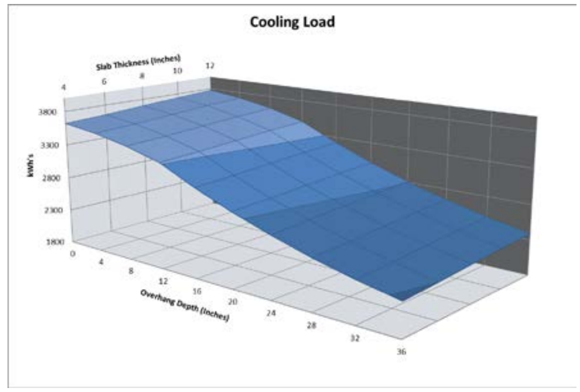


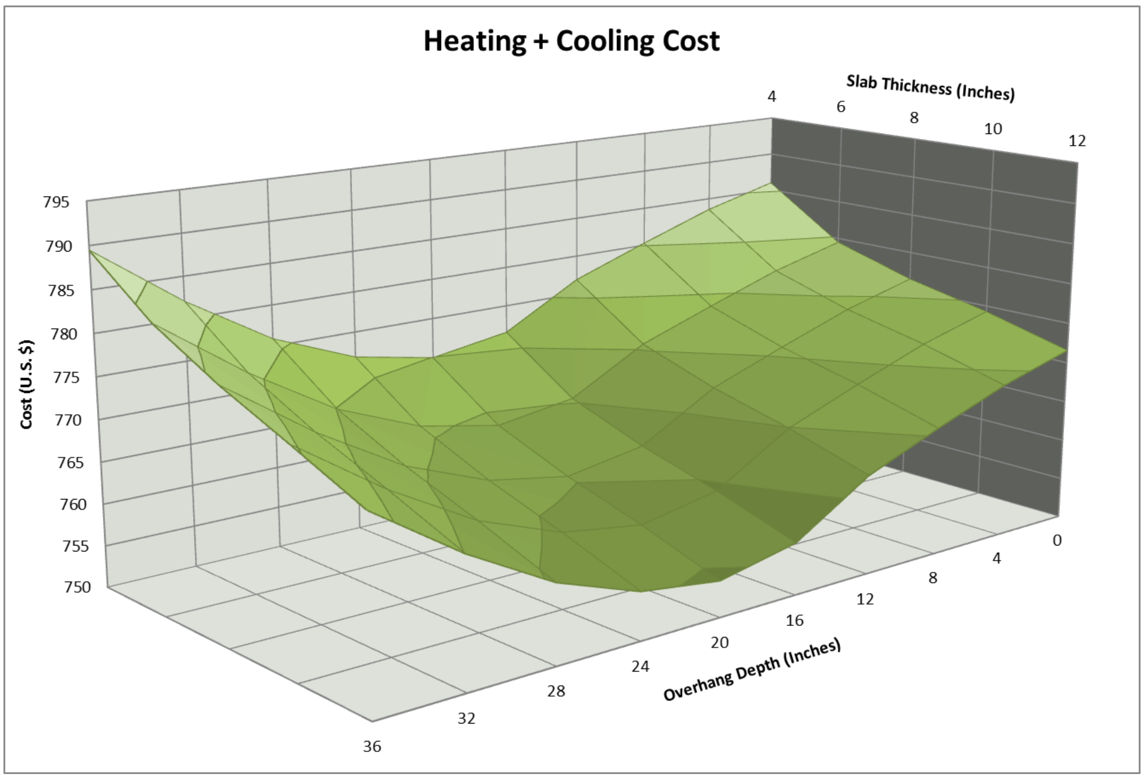


With a WWR of 20.6 the minimum cost of $761 occurs with a 12” Slab and a 16” Overhang.

23.3 WWR:

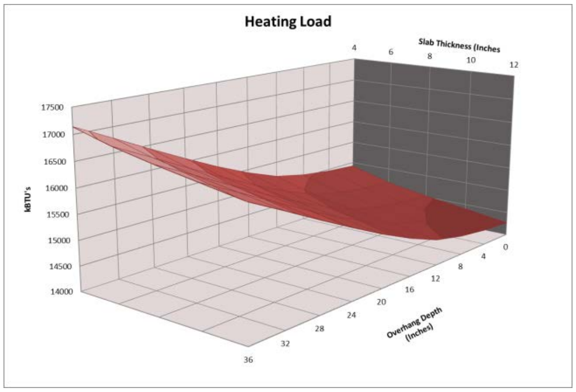


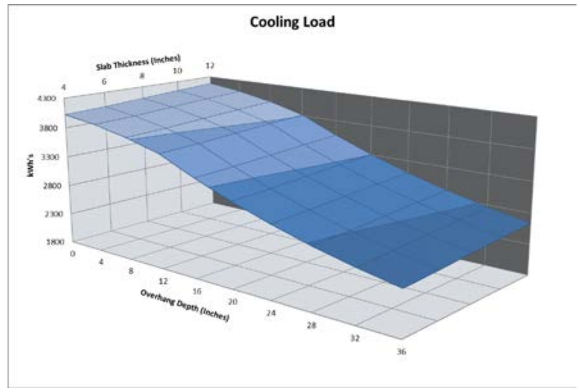


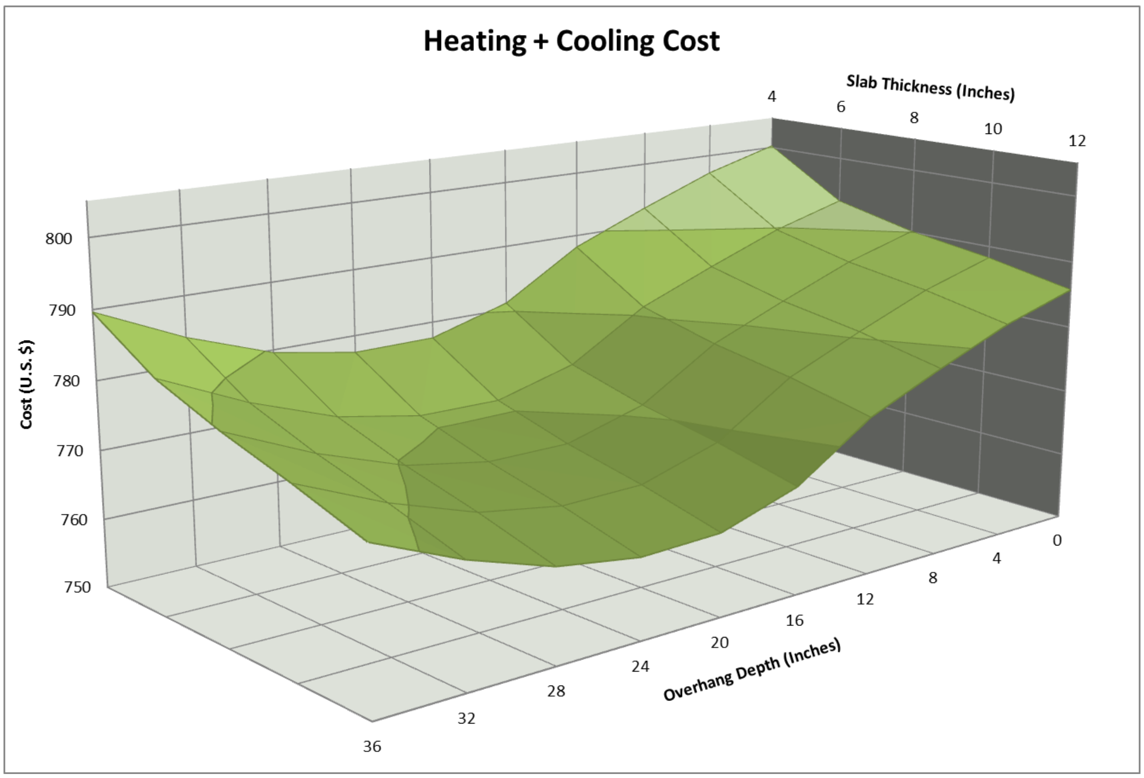


With a WWR of 23.3 the minimum cost of $754 occurs with a 12" Slab and a 20" Overhang.

26 WWR:



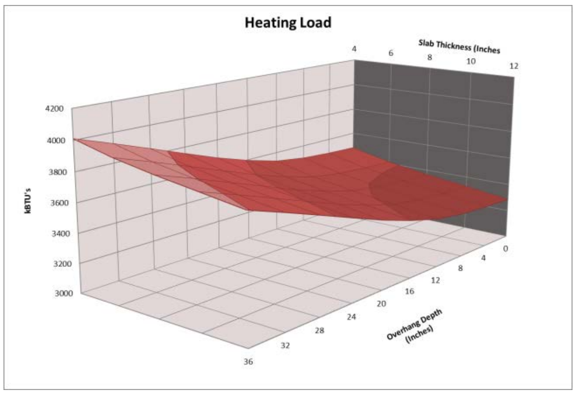


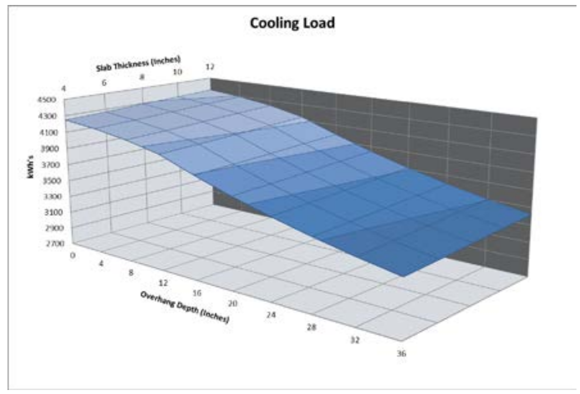


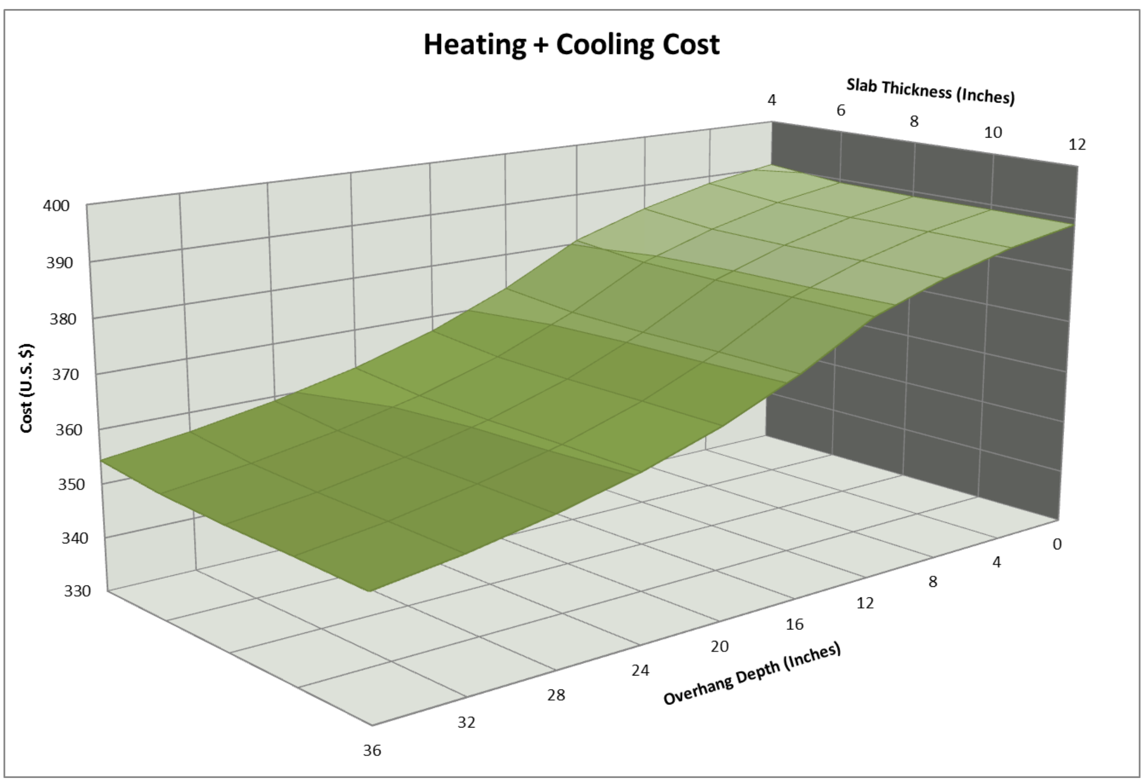
With a WWR of 26 the minimum cost of $761 occurs with a 12” Slab and a 21” Overhang.

Passive House

<u>12.4 WWR:</u>

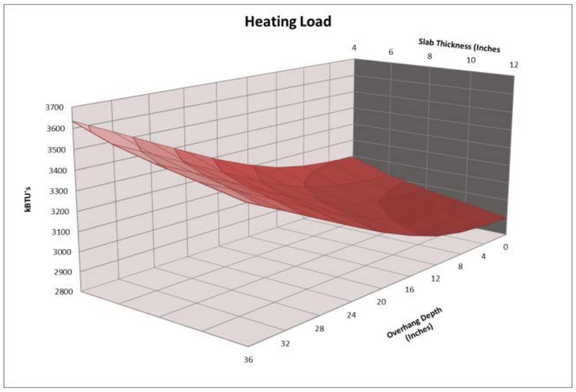


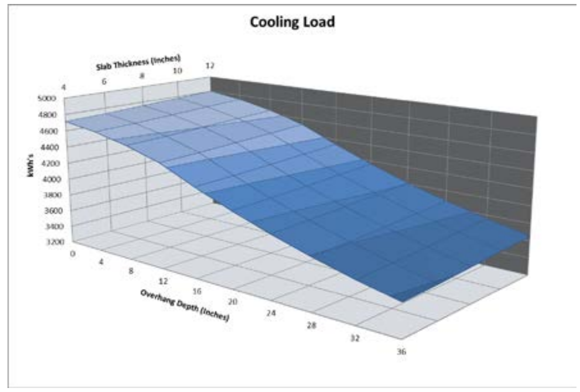


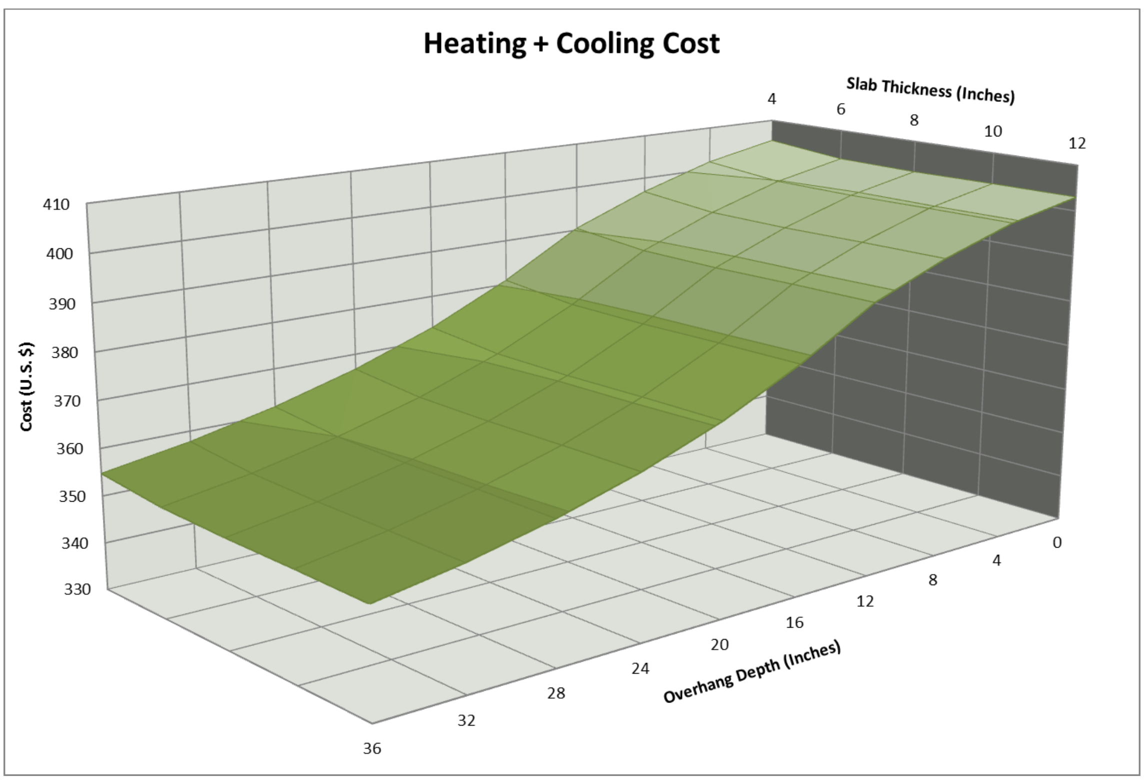


With a WWR of 12.4 the minimum cost of $351 occurs with a 12” Slab and a 36” Overhang.

15.1 WWR:

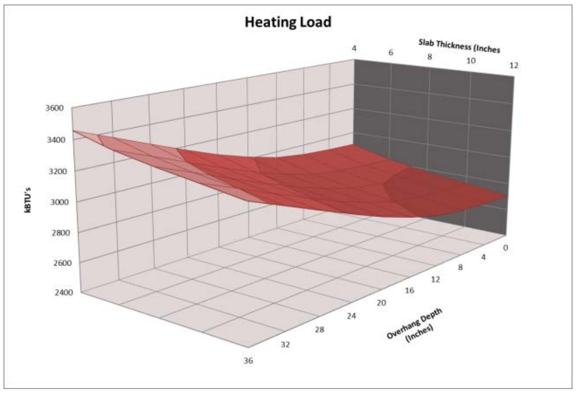


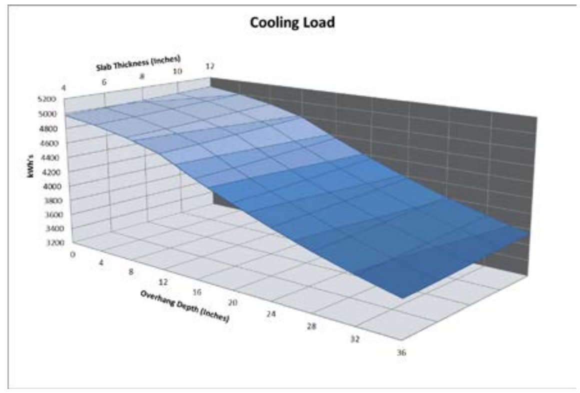


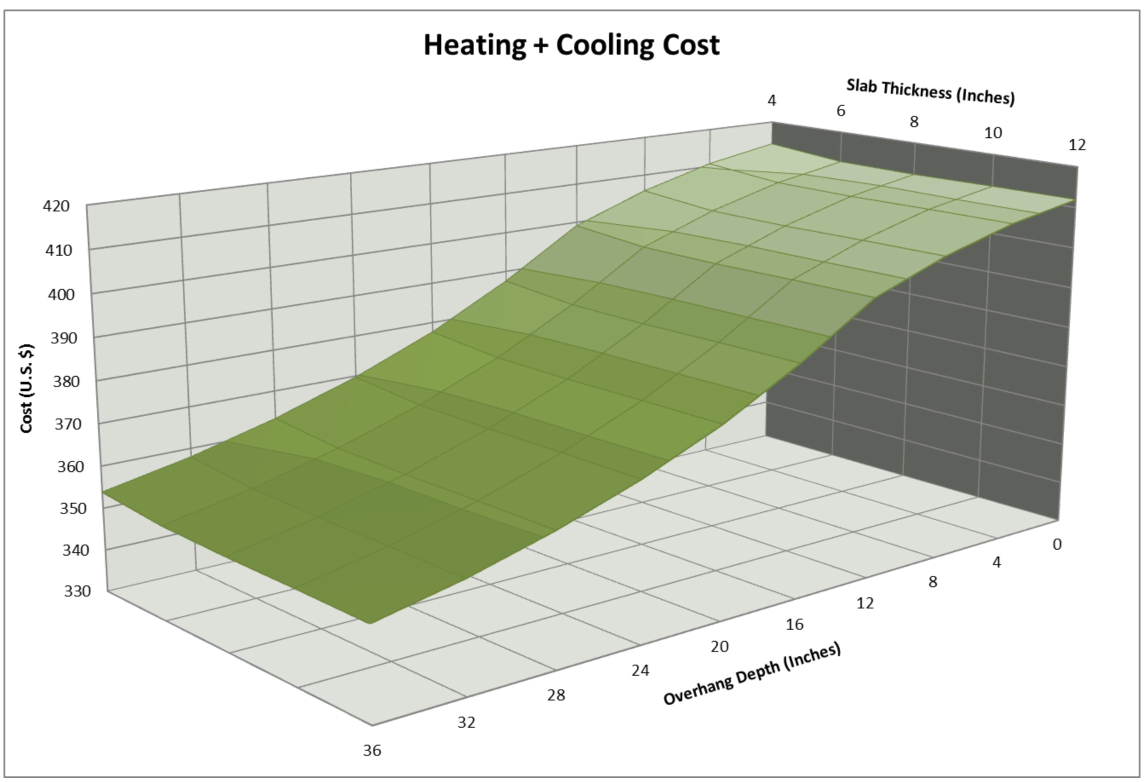


With a WWR of 15.1 the minimum cost of $352 occurs with a 12” Slab and a 36” Overhang.

17.8 WWR:

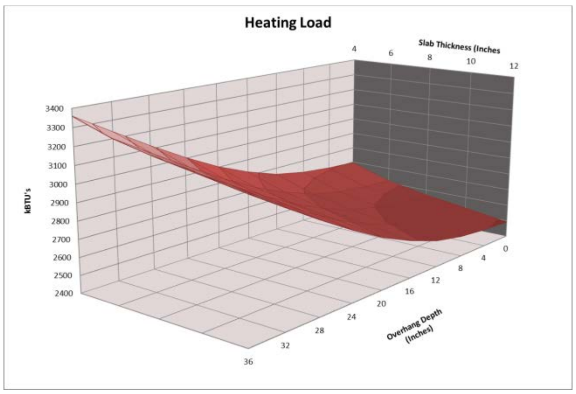


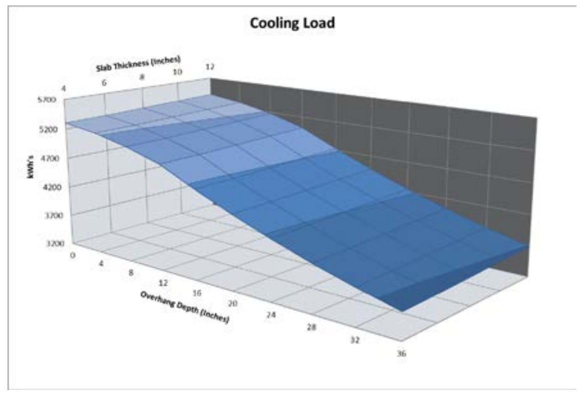


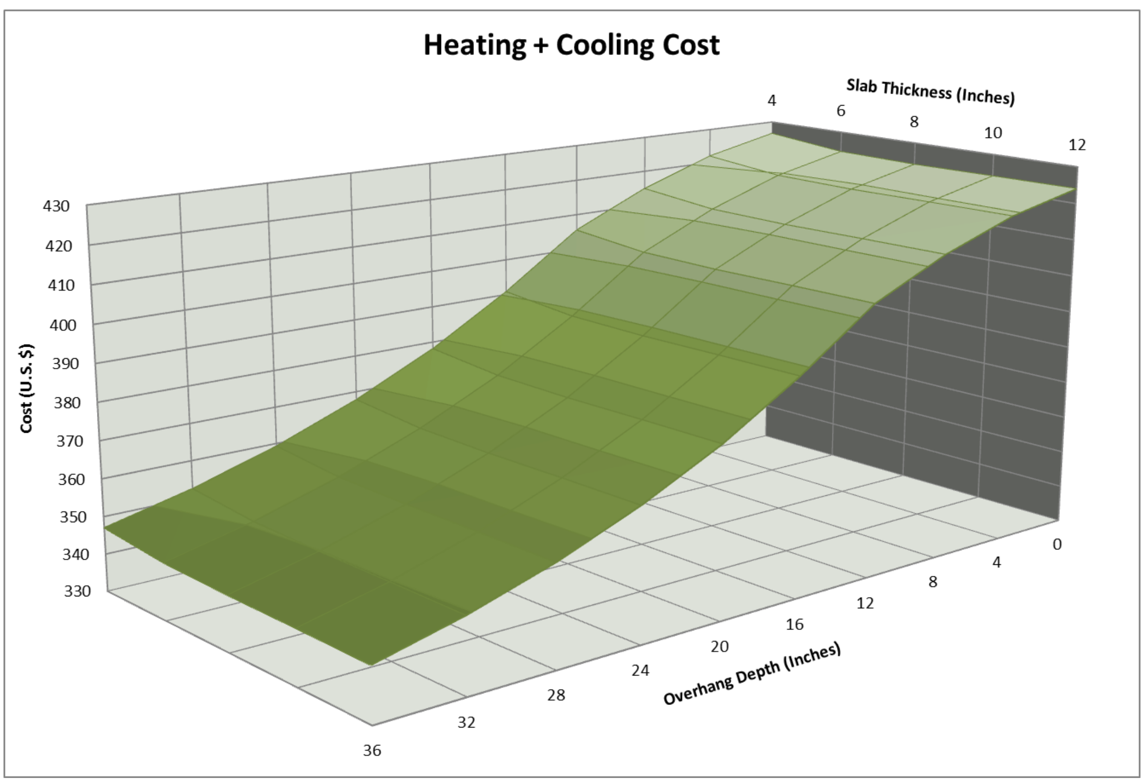


With a WWR of 17.8 the minimum cost of $351 occurs with a 12” Slab and a 36” Overhang.

20.6 WWR:

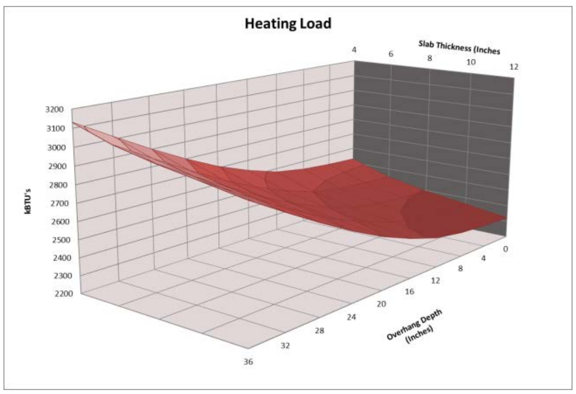

Heating Load
Slab Thickness (Inches
4
6
8
10
12
kBTU's
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
Overhang Depth (Inches)
0
4
8
12
16
20
24
28
32
36

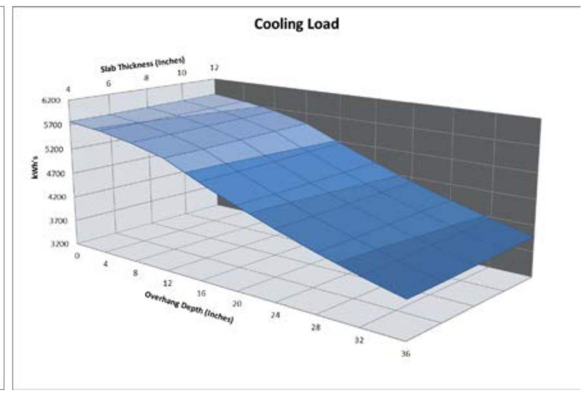

Cooling Load
Slab Thickness (Inches)
4
6
8
10
12
kWh's
5700
5200
4700
4200
3700
3200
Overhang Depth (Inches)
0
4
8
12
16
20
24
28
32
36

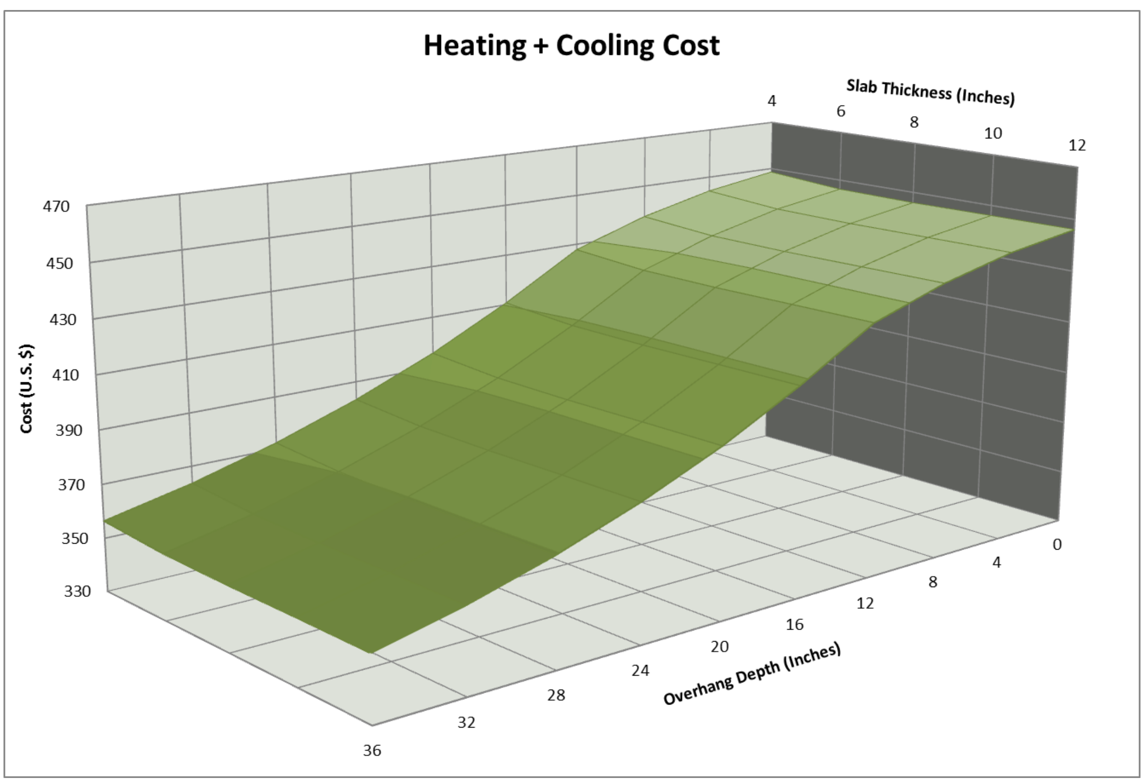

Heating + Cooling Cost
Slab Thickness (Inches)
4
6
8
10
12
Cost (U.S.$)
430
420
410
400
390
380
370
360
350
340
330
Overhang Depth (Inches)
0
4
8
12
16
20
24
28
32
36

With a WWR of 20.6 the minimum cost of $344 occurs with a 12” Slab and a 36” Overhang.

23.3 WWR:

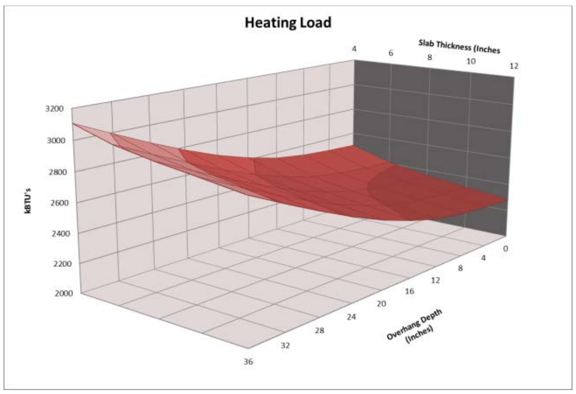


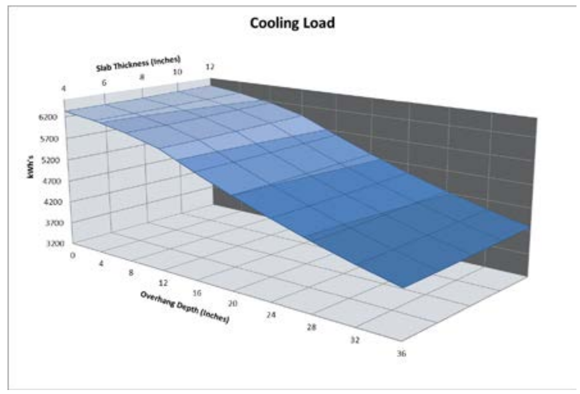


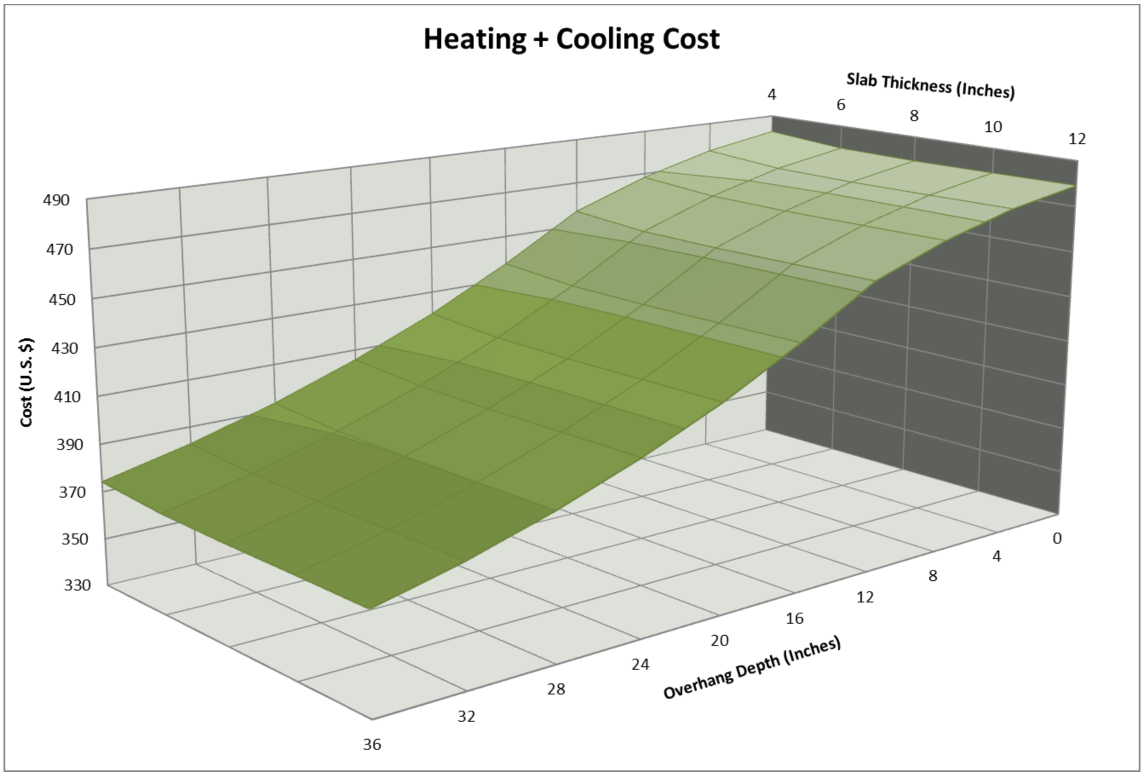


With a WWR of 23.3 the minimum cost of $353 occurs with a 12" Slab and a 36" Overhang.

26 WWR:







With a WWR of 26.6 the minimum cost of $371 occurs with a 12” Slab and a 36” Overhang.

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(http://www.ornl.gov/sci/roofs+walls/research/detailed_papers/thermal/index.html)

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